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WING DATA AND ANALYSIS FOR A STAGGERED BIPLANE.*

BY

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PART I.—GENERAL DISCUSSION.

In the JOURNAL OF THE FRANKLIN INSTITUTE for June, 1913, the present writer analyzed the chief stresses sustained by the wing framing of a common orthogonal [1] biplane in straight and in curvilinear flight. The method there developed was applied to a standard Wright and a standard Curtis biplane of that period. To supplement that treatment we may suppose that the planes are staggered, that the spars are continuous from body to wing tip, and that the angle of incidence varies with the speed, thus causing the line of resultant lift to travel. The analysis may be made more complete and more serviceable to the designing draughtsman or engineer by finding the actual distribution of the loads and stresses in a staggered wing during flight at its highest and lowest speeds and angles of incidence. The basic data may be taken from present-day practice.

* Communicated by the Author.

[1] An orthogonal biplane is one whose upper plane is, in normal flight, directly over the lower plane. A staggered biplane has its upper plane placed somewhat forward or aft of the lower one. The first kind has its struts approximately vertical; the second has its struts sloping forward or backward.

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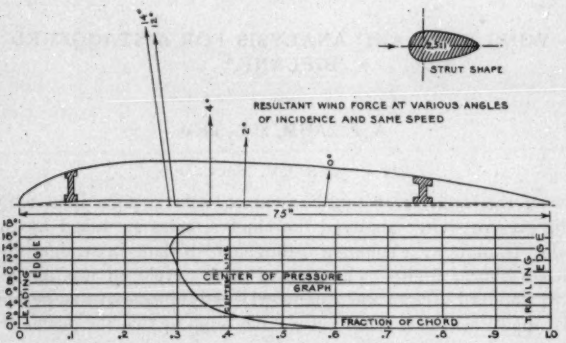
Given Dimensions.—We may assume that the planes of the wing are parallel, of the same size and shape, the upper one placed 40 per cent. of the gap ahead of the lower. Numerically let us assume the length from fuselage to wing tip 231 inches; the chord length and gap each 75 inches; the section contour as shown in Fig. 1, and known in England as the Royal Air Craft shape No. 6, or R.A.F. 6; the whole length of each plane from tip to tip 41 feet; the whole weight of each plane 129 pounds; the whole weight of machine and load 2190 pounds. These figures are taken from the specifications of an actual biplane.

FIG. 1.



Sections of wing and strut shapes. Wind force on wing planes, in magnitude and position, for various incidences.

Aërodynamic Data.—The resultant wind force on a monoplane wing of the foregoing shape is completely determined by the data of Table I, obtained from wind-tunnel measurements made at the British National Physical Laboratory [2] for the conditions assigned in the table. From these data the resultant wind force for various angles of incidence is plotted in Fig. 1; also the lift and the ratio life/drift are plotted in the diagram of Fig. 2. The wind forces at any other speed are to these in proportion to the square of the speed of the wing relatively to the air. For a biplane of the same area the wind force is 82 per cent. as much, if there

[2] See report for 1912–13 of the British Advisory Committee for Aëronautics.

TABLE I.—*Characteristic Data for Monoplane Wing Shape. Air at 15° C.—760 mm. Aspect Ratio 6/1. Average Lift of Staggered Biplane Equals 87 per cent. of Tabulated Values.*

Angle of incidence	0°	2°	3°	4°	5°	6°	8°	10°	12°	14°	16°	18°
Lift in pounds per square foot at 60 feet per second	.993	1.911	2.195	2.419	2.819	3.166	3.752	4.328	4.886	5.009	5.061	4.919
Lift to drift ratio	8.5	16.3	17.6	17.1	16.5	15.6	14.2	12.5	11.5	9.7	7.5	4.3
Centre of pressure in per cent. of chord depth	.375	.425	.....	.358	.....	.329	.312	.302	.292	.280	.295	.330

TABLE II.—*Assembled Dimensions and Computed Values.*

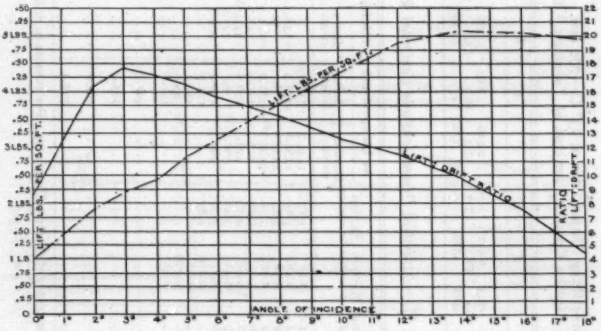
Symbol	Member	Material	Sectional Area	Moment of inertia	Section modulus	At low speed and ∠ of incidence of 12°				At high speed and ∠ of incidence of 0.5°			
						Bending moment	Lift stress	Drift stress	Factor of safety	Bending moment	Lift stress	Drift stress	Factor of safety
A	Front spar	Spruce	4.02	8.18	3.85	1434.8	387.87	0.	13	597.1	172.1	0.	30
B	Front spar	Spruce	4.02	8.18	3.85	1434.8	1058.3	−148.3	10	597.1	469.8	−260.2	16
C	Front spar	Spruce	4.02	8.18	3.85	1434.8	0.	0.	19	488.5	0.	0.	47
D	Front spar	Spruce	4.02	8.18	3.85	1434.8	−387.9	−121.3	33	488.5	−172.1	−212.9	27
E	Rear spar	Spruce	5.26	5.41	3.57	478.3	129.3	148.3	32	1194.3	344.2	260.2	13
F	Rear spar	Spruce	5.26	5.41	3.57	478.3	352.8	247.56	24	1194.3	939.7	434.2	10
G	Rear spar	Spruce	5.26	5.41	3.57	391.3	0.	121.3	45	977	0.	212.2	17
H	Rear spar	Spruce	5.26	5.41	3.57	391.3	129.3	202.3	48	977	−344.2	355.3	21
I	Lift strut	Spruce	....	0.416	3.57	....	135.6	.....	7	....	60.2	....	16
J	Lift strut	Spruce	....	1.41	....	....	452.4	....	7	....	201	....	17
K	Lift strut	Spruce	....	0.416	....	....	45.2	....	22	....	120.4	....	8
L	Lift strut	Spruce	....	1.41	....	....	150.8	....	22	....	402	....	8
M	Lift cables	Soft Roebling steel	....	....	....	....	490.7	....	....	....	218.2	....	....
N	Lift cables	Soft Roebling steel	....	....	....	....	925.4	....	....	....	421.2	....	....
O	Lift cables	Soft Roebling steel	....	....	....	....	163.6	....	....	....	436.1	....	....
P	Lift cables	Soft Roebling steel	....	....	....	....	308.4	....	....	....	822.3	....	....

REMARKS: Factors of safety are given for points of greatest fibre stress. For stresses in drift wires and struts see drift diagrams.

be no stagger, and 87 per cent. as much with a 40 per cent. stagger; also the upper plane lifts about 10 per cent. more than the lower one. For want of more exact information, we shall assume the line of the resultant wind force on each plane to be as given by Table I and illustrated in Figs. 3 and 4.

Gross Loading and Limiting Angles of Incidence.—Since the upper plane lifts 10 per cent. more than the under one, we can assume them to bear, respectively, 55 and 45 per cent. of the whole load,—that is, $4190 \times .55 = 1204.5$ pounds, and $4100 \times .45 = 985.5$ pounds, respectively. If the limiting speeds of the aëroplane are to be about 40 and 80 miles an hour, the corresponding angles

FIG. 2.



Aërodynamic data and diagram for wind force on wing plane.

of incidence are found by aid of Table I to be respectively 12° and 0.5°. Thus at 12° incidence and 50 feet a second, or about 40 miles an hour, the tabulated lift, multiplied by 87 per cent., is 4.25 pounds per square foot, and this, multiplied by the given wing area, equals the gross weight of the aëroplane; similarly for 80 miles an hour and 0.5° incidence.

Figs. 3 and 4 show the whole wind lift and drift on the supporting planes at the limiting angles, the drift equalling the known lift multiplied by the lift/drift ratio given in Table I and plotted in the diagram. The whole lift and the whole wind force, or resultant of lift and drift, differ from each other by less than half a per cent. for all angles from 0.5° to 12°. This can easily be

shown, since for all these angles the drift is not more than one-tenth of the lift. Thus if the lift be 1, and the drift 0.1, their resultant is $\sqrt{1^2+0.1^2}=1.005$.

Spacing of the Wing Spars.—Fig. 1 shows that, as the wing incidence varies throughout its assumed range of 0.5° to 12°, the "centre of pressure" moves fore or aft through about one-fourth the chord. Hence, if the spars be placed too near together, each in turn may have to sustain the whole load. The farther apart they are spaced the less their portion of the load varies. In the wing under consideration the spars can be placed 48 inches apart and yet have sufficient depth within the canvas. Accordingly the front spar is placed 9 inches from the leading edge of the plane, and the rear spar 18 inches from the trailing edge. The shape and positioning of the spars are as shown in the figure. With this spacing the front spar bears three-fourths of the wind force at 12° and one-half at 0.5°.

Running Loads.—The left-hand diagrams of Figs. 3 and 4 show the running loads on the individual sustaining planes, expressed in pounds of resultant force of wind and gravity on each running inch of the wing length. Thus the resultant or net vertical running lift of wind and gravity on the upper plane equals $(L-W)/l=(1204.5-129)/492=2.186$ pounds per inch, in which L is the gross lift on the plane, W is its weight, l its length in inches. The net running drift at 0.5° and 12° equals the gross running lift divided by the lift/drift ratio for those angles. At both angles the gross running lift equals $1204.5 \div 492 = 2.45$, very nearly. Hence at 0.5° the net running drift equals $2.45/10.375 = 0.236$, and at 12° it equals $2.45/11.5 = 0.213$, the divisors being the lift/drift ratios for 0.5° and 12°, respectively. In finding this net drift the wind force on the plane alone has been taken, that on the struts and wires being ignored for the present.

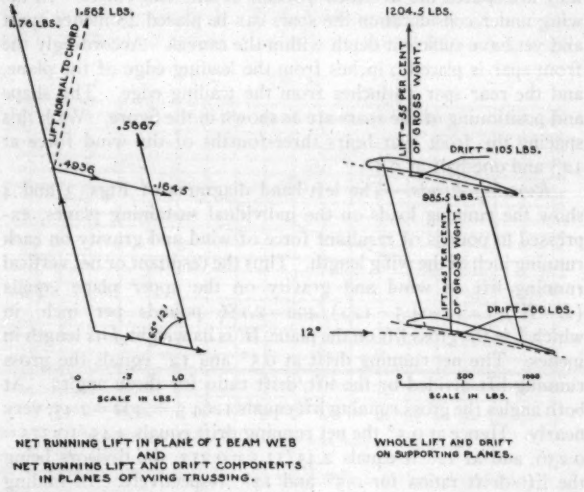
For simplicity the running load is assumed to be uniform from tip to tip of the wings. In reality there is some 10 per cent. decline of running load at the wing ends, and an increase at mid-wing due to the propeller stream. These and many other details must be comprised in a minute wing analysis.

Since, as already explained, the front spar bears three-fourths of the wind force at 12° and one third at 0.5°, it bears at these angles running lifts of $2.186 \times \frac{3}{4} = 1.64$, and $2.186 \times \frac{1}{3} = 0.729$, and running drifts of $.213 \times \frac{3}{4} = .160$, and $.236 \times \frac{1}{3} = .079$; and

similarly for the rear spars at those incidences. The running loads on the lower spars are $45/55 = 9/11$ of those on the corresponding upper spars.

These running loads have been graphically resolved, as shown in Figs. 3 and 4, in the plane of the front struts and in the plane of the top spars, to obtain the running loads in those planes, and thence the tensions and compressions borne by the truss members

FIG. 3.


1.562 LBS.
1.76 LBS.
LIFT NORMAL TO CHORD
.5867
.4936
.1645
64° 12'
0 .5 1.0
SCALE IN LBS.
NET RUNNING LIFT IN PLANE OF I BEAM WEB AND NET RUNNING LIFT AND DRIFT COMPONENTS IN PLANES OF WING TRUSSING.
1204.5 LBS.
LIFT = 55 PER CENT OF GROSS WGHT.
DRIFT = 105 LBS.
985.5 LBS.
LIFT = 45 PER CENT OF GROSS WGHT.
DRIFT = 86 LBS.
12°
0 500 1000
SCALE IN LBS.
WHOLE LIFT AND DRIFT ON SUPPORTING PLANES.

Whole lift and drift on wing planes at 12° incidence. Running lift and drift resolved in truss planes.

in those planes. Likewise they have been resolved in the plane of the spar web in order to find the bending moment on the spar due to the net running load on it.

Spacing of the Struts along the Spars.—The distances between the struts along the wing may be so chosen as to make the bending moment in any spar the same at all its strut joints. Thus the overhanging wing end is a uniformly loaded cantilever beam whose bending moment next the strut is $wl/12$, if w be the known running load on the spar, and l the length of the overhang. The

next span is a uniformly loaded beam with fixed ends, and next to each strut has the bending moment $wl_1^2/12$, l_2 being its length. The next span is a uniformly loaded beam fixed next to the strut and pinned at the engine section; and next to the strut has the bending moment $wl_3^2/8$, l_3 being its length. Now, since these three moments all are to be equal,

$$\frac{wl_1^2}{2} = \frac{wl_2^2}{12} = \frac{wl_3^2}{8}$$

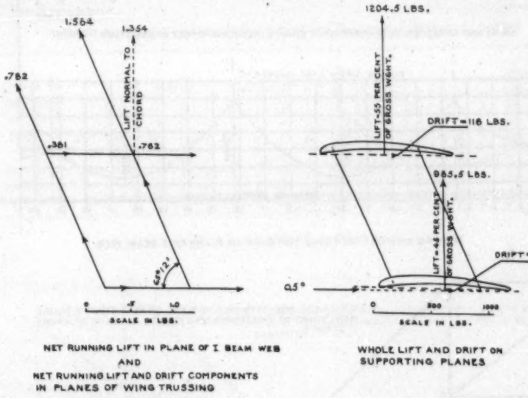
Also, since the sum of the span lengths equals the given wing length,

$$l_1 + l_2 + l_3 = l$$

Solving these equations, we find

$$l_1 = .1855\ l;\ l_2 = .4535\ l;\ l_3 = .5710\ l \ldots\ldots\ldots (A)$$

FIG. 4.



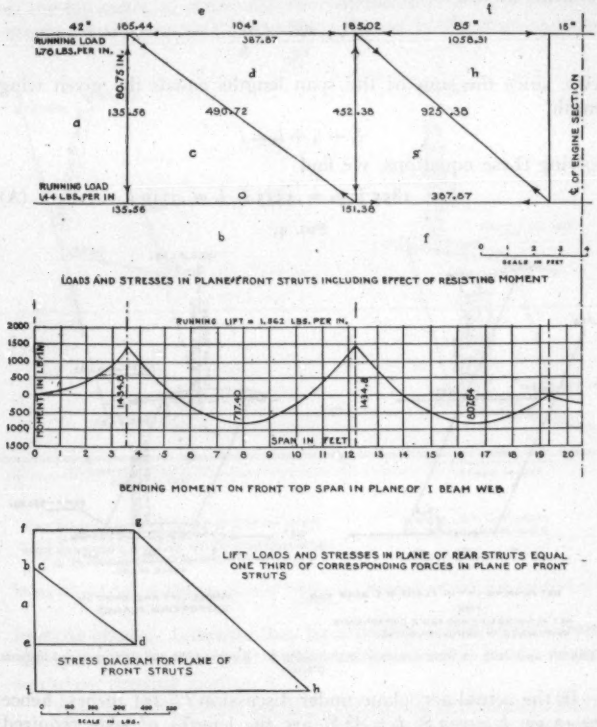
Whole lift and drift on wing planes at 0.5° incidence. Running lift and drift resolved in truss planes.

In the actual aëroplane under discussion $l = 231$ inches; hence $l_1 = 42.42$, $l_2 = 103.8$, $l_3 = 84.8$, are the lengths of span required to make equal bending moments in the spars at the strut joints. Actually the spans were made 42 inches, 104 inches, 85 inches in length.

A more general method of finding the bending moments in a

continuous beam, and hence of spacing the struts so as to give equal moments next to them, is Clapeyron's theorem of three moments. For the type of aëroplane here considered, however, equations (A) are simpler and more expeditious.

FIG. 5.

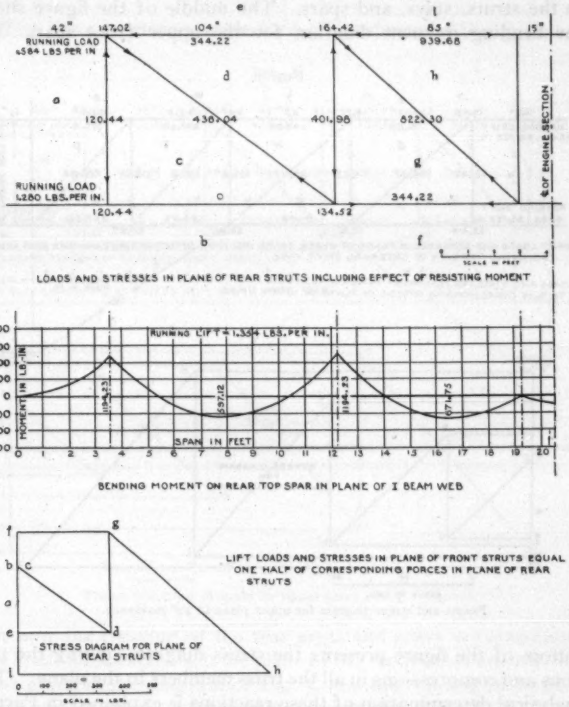


Frame, stress, and moment diagram for plane of front struts at 12° incidence.

General Character of Wing Loads and Stresses.—The running loads or forces outlined in Figs. 3 and 4 are entirely external forces, and beget within the wing framing various bending mo-

ments, tensions, and compressions, which are now to be found. The fore-and-aft diagonal wires, having no external hold, can offer no resistance to the wind lift and drift, but only to a change of parallelism of the spars. The wind lift and drift are borne

FIG. 6.

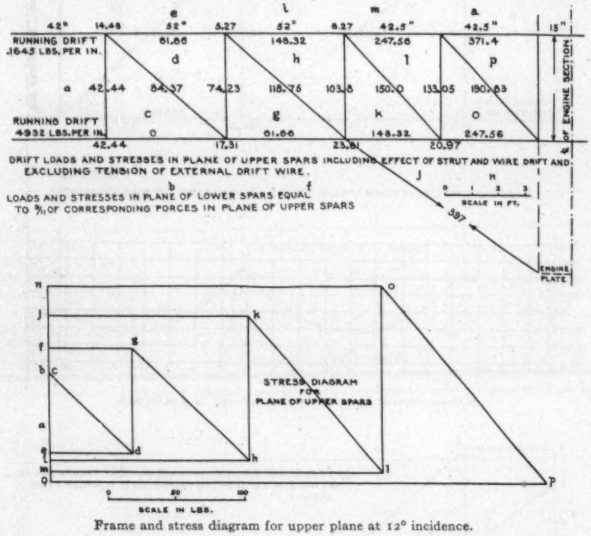


Frame, stress, and moment diagram for plane of rear struts at 0.5° incidence.

by the trussing in the four geometric planes containing, respectively, the front posts, the rear posts, the upper spars, the lower spars. We may now analyze the forces and reactions in these four planes. The stresses are written in pounds, the moments in pound-inches.

Applied Forces and Reactions in the Planes of the Struts.—The trussing in the plane of the front spars and struts, together with the applied forces and reactions at 12° incidence, is shown in Fig. 5. The upper part of the figure shows the distribution of the loads, as derived from Fig. 3, and the resulting endwise stresses in the struts, stays, and spars. The middle of the figure shows the bending moment diagram for the upper front spar. The

FIG. 7.



Frame and stress diagram for upper plane at 12° incidence.

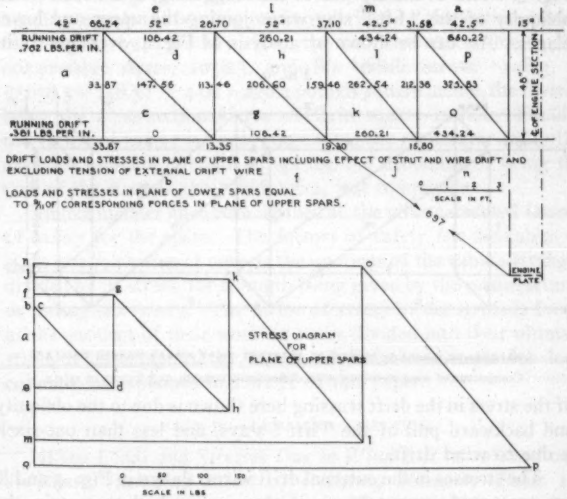
bottom of the figure presents the stress diagram, giving the tensions and compressions in all the truss members in the plane. The analytical determination of these reactions is explained in Part II of this article; the graphical analysis needs no explanation. The stays omitted from the frame diagram sustain in flight no stress due to the wind force unless this be exerted on top of the planes, as when a sudden downward puff occurs.

From the three diagrams in Fig. 5 like ones for the other

geometric planes and for the same incidence can be sketched by simple comparison. Thus the loads and reactions in the plane of the rear struts equal one-third of those in the diagram for the corresponding forces in the plane of the front struts; the bending moment acting on either bottom spar is 9/11 of that in the spar above it.

Fig. 6 is a repetition, made for 0.5° incidence, of Fig. 5, except

FIG. 8.


RUNNING DRIFT .702 LBS. PER IN.
RUNNING DRIFT .381 LBS. PER IN.
DRIFT LOADS AND STRESSES IN PLANE OF UPPER SPARS INCLUDING EFFECT OF STRUT AND WIRE DRIFT AND EXCLUDING TENSION OF EXTERNAL DRIFT WIRE
LOADS AND STRESSES IN PLANE OF LOWER SPARS EQUAL TO 9/11 OF CORRESPONDING FORCES IN PLANE OF UPPER SPARS.
SCALE IN FT.
ENGINE PLATE
STRESS DIAGRAM FOR PLANE OF UPPER SPARS
SCALE IN LBS

Frame and stress diagram for upper plane at 0.5° incidence.

that now the trussing of the rear posts and spars is represented. The loads and reactions in the plane of the front posts are one-half those given in the diagram of Fig. 5, and the bending moment in either bottom spar is 9/11 that in the spar above it.

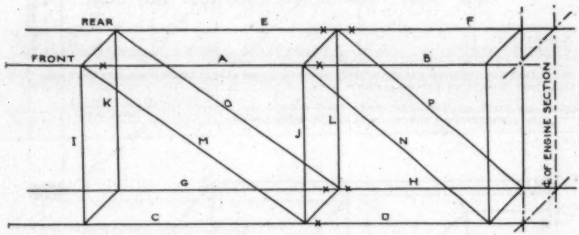
Applied Forces and Stresses in the Upper and Lower Planes.—The trussing in the plane of the upper spars, together with the applied forces and stresses at 12° incidence, is shown in Fig. 7. The upper diagram of the figure gives the distribution of loads for that plane, as derived from Fig. 3; also the endwise stresses

in the "drift" struts and stays and in the spars. The bending moments in the spars in this case are ignored as insignificant. The bottom of the figure presents the stress diagram for the upper plane in question.

Fig. 8 is a repetition, made for 0.5° incidence of Fig. 7, and requires no special explanation.

Particular attention may be directed to the great magnitude of the compressive stress, 650 pounds, in the upper rear spar in Fig. 8. This is mainly due to the staggering, and hence to the obliquity of the "lift" stay wires joining the upper and lower planes. As can be shown by analysis of Fig. 4, over five-sixths

FIG. 9.



REFERENCE DIAGRAM—POINTS OF GREATEST FIBRE STRESS MARKED THUS "X"

Conspectus of wing members, with dimensions, stresses, and factors of safety.

of the stress in the drift trussing here shown is due to the obliquity and backward pull of the "lift" stays, and less than one-sixth is due to wind drift.

The stresses in the external drift wires, shown in Figs. 7 and 8, are computed separately, as if these wires had to sustain the entire rearward pull on the wing. The method of computation is given in Part II of this article.

The applied loads and stresses in the lower plane are 9/11 of the corresponding ones just found for the upper plane.

Assembled Dimensions and Computed Values.—Fig. 9 shows in perspective the wing members which bear the chief fibre stresses, and Table I contains the chief specifications and computed values for those members. The ultimate object of this table is to bring out the factors of safety for the parts of the wing framing subject to the greatest fibre stress. The unit stresses for 12° in-

cidence, derived from columns 4, 6, 7, 8, 9, are algebraically added, then divided into the ultimate strength of the material to obtain the factor of safety tabulated in the tenth column; similarly for the columns which apply to 0.5° incidence.

As an example, let us find from these columns the factor of safety for the spar member B, at the point marked ×. By columns 6 and 7 the unit fibre stress in B, due to the bending moment caused by the running load, is $1434.8 \div 3.85 = 372.7$ pounds per square inch, since the greatest fibre stress at any section of a beam, due to bending, equals the bending moment divided by the section modulus. Again, by columns 4, 8, 9, the unit fibre stress due to B's compressive stress, 1058.3, and B's tensile stress, −148.3, is $(1058.3 - 148.3) \div 4.02 = 226.4$ pounds square inches, the divisor being the cross-sectional area of B in square inches. Finally, the factor of safety is $6000/599.1 = 10$, the numerator being the assumed ultimate strength of spruce, the denominator being the sum of the stresses 372.7 and 226.4, just computed.

In like manner have been derived all the other tabulated factors of safety for the spars. The factors of safety for the cables or stays can be written at once as the quotient of the cable's strength divided by its stress, the strength being given by the manufacturer or testing laboratory. The factor of safety of the struts is found as the quotient of their working stress divided into their ultimate strength as computed by means of Euler's formula for long columns, as explained in Part II of this paper.

PART II.—DETAILED ANALYSIS.

Wing Loads and Stresses Due to Wind Lift at 12° and 0.5° Incidence, Including Effect of Resisting Moment.—From the running loads on the spars shown in Fig. 5, the lift exerted by these spars on the struts joining them is found to have the numerical values marked at the strut joints. The loads and stresses are expressed in pounds.

Thus the bottom of the outer strut sustains all the running load on the lower spar from its outer tip to the centre of the middle span, a distance of $42 + 104/2 = 94$ inches. This lift, therefore, equals $94 \times 1.44 = 135.56$ pounds. Similarly the top of the same strut is lifted with a force of $94 \times 1.76 = 165.44$ pounds. In proof of these statements it may be observed that the middle span, being a uniformly loaded beam with fixed ends, is known to have its

shearing force equal to zero midway between the struts. This means that if the spar were severed at the middle of this span the lift of its 94-inch segment would balance on the strut and hence would exert its whole lift there.

The span next the engine section has its point of no shear at a distance of five-eighths of its length to the right of the strut, or $85 \times \frac{5}{8} = 53.125$ inches. Hence the lift exerted on the bottom of this strut by the lower spar is $(52 + 53.125)\ 144 = 151.38$ pounds. Similarly the top of the same strut is lifted with a force of $151.3 \times 11/9 = 185.02$ pounds.

Having now the values of all the applied wind lifts concentrated at the joints of the given frame, we can proceed to find the resisting tensions and compressions in the frame members. The values of these stresses, as found from the stress diagram in the bottom of Fig. 5, and checked by computation, are marked in the frame diagram.

A similar analysis applies in the case of 0.5° incidence, as shown in Fig. 6.

Bending Moment on the Spars Due to Wind Lift.—Since the spars are assumed to have a uniform running load, the bending moment at all the points of their length can be found from the well-known properties of familiar types of beams. The moments here found are expressed as pound-inches.

Thus the overhang at the outer end of each plane can be treated as a uniformly loaded cantilever beam, whose maximum bending moment is $wl^2/2$, w being the running load, l the length. Hence for the front top spar just outside the strut the bending moment is $1.76 \times 42^2/2 = 1434.8$ pound-inches. This value is plotted as a positive ordinate in the bending moment diagram in Fig. 5, together with values similarly found for intermediate points on the cantilever. The points lie on the curve—a parabola—to the left of the line of the outer strut.

Again, the bending moment at each end of the mid-span is, by express design, 1434.8, and at its middle is, by the formula for such a beam, minus one-half of $1434.8 = -717.4$, pound-inches. By the formula for such a beam, the moment is zero at one-fifth the distance from either end of it, or, more exactly, at .2113 l, where l is its length. Thus we have five points on the bending moment curve—a parabola—and easily draw it, as shown in the figure between the two strut positions.

The bending moment for the span next the engine section is 1434.8 at the strut, 0 at the pin joint on the fuselage, 0 at one-fourth its length to the right of the strut, and at $\frac{5}{8}$ of its length is 9/16 of its greatest value, or $9/16 \times 1434.8 = 807.64$ pound-inches.

For corresponding points at 12° incidence, the bending moment on the rear top spar is one-third that on the front one; the moment on the bottom spars is 9/11 that on the corresponding top spars.

For the case of 0.5° incidence the bending moment diagram, obtained for one of the spars in an analogous way, is shown in Fig. 6, and the diagrams for the remaining spars can be constructed as before by merely changing the scale. Thus at 0.5° incidence the moments on the front spar are one-half those on the rear one; the moments in the bottom spars 9/11 of those above.

Wing Loads and Stresses Due to Drift at 12° and 0.5° Incidence, Excluding Effect of Resisting Moment but Including Drift on Struts and Stays.—Figs. 7 and 8 show the frame and stress diagrams for the internal trussing of the upper plane. In finding the resultant effect of the running load, considered as applied at the frame joints, no regard is paid to the influence of the stiffness or resisting moment of the beam, since this is slight. In fact, the spar is treated as if pin-jointed at all the various intra-canvas struts and stay connections, excepting at the outer post, where it is considered continuous. The drift of the wind on the struts and wires is assumed to add at each external strut joint a horizontal force of half a pound at low speed and two pounds at high speed. A similar treatment applies to the lower plane.

This premised, the 94 inches length of overhang and first span in Fig. 8 bears a resultant wind drift of $94 \times .4932 = 46.36$ pounds at its middle, or 5 inches from the outer joint, and 47 inches from the next joint; and it exerts upon these joints, respectively, the pressures $46.36 \times 47/52 = 41.9$, and $46.36 \times 5/52 = 4.46$. To the first of these must be added half a pound drift for the strut and stay, making 42.4 pounds; and similarly for the corresponding portion of the rear spar.

The aggregate wind drift on each of the other spans is divided into halves, and each of the other inter-canvas struts within the restraining plane is assumed to bear one-half of the wind drift on its two adjoining spans. At each joint where an external strut

joins the spar an extra half pound is added for the wind drift of strut and wire.

In this way were obtained all the external applied forces marked numerically at the joints of the frame diagram. Now, having the dimensions and loads of the frame diagram, the stresses,—that is, tensions and compressions,—in the members of the frame can be found graphically and analytically by the usual procedure in mechanics. The treatment is quite analogous for the higher speed and 0.5° incidence, in which case the strut and stay drift to be added at each strut joint is 2 pounds.

The bending and resisting moments are ignored in Figs. 8 and 9, as being very slight. Also the influence of the external drift wire is ignored in the computation of the frame stresses; then in turn this wire is assumed to bear all the drift on the wing, and its tension is computed on that assumption.

The external drift wire is regarded as the diagonal of a right prism whose horizontal sides, given in the figure, are 85 and 60 inches, and whose vertical side is 60 inches; that is, the diagonal is 115 inches long. Hence the tension in this forward-and-downward-drawn wire must be 115/60 of the forward pull it exerts on the wing. But, by taking moments about the wing root, this forward pull can be found from the given applied forces to be 209.7 pounds at 12° incidence, and 376 pounds at 0.5° incidence. Hence, finally, the tension in the external drift wire is $209.7 \times 115/60 = 397$ pounds at 12°, and $367 \times 115/60 = 697$ pounds at 0.5° incidence, as given in Figs. 8 and 9.

Sections, Strengths, and Factors of Safety of Spars and Struts.—From the linear dimensions of the beam section shown in Fig. 1 the area, moment of inertia, and section modulus are computed by the methods of elementary mechanics, and tabulated respectively in columns 4, 5, and 6 of Table II. These are used, together with the stress and moment columns, to find the factor of safety, in the manner already explained and illustrated.

The moment of inertia of the mid-sections of the struts, illustrated in Fig. 1, is obtained by comparison with that of a standard strut one inch thick, whose moment of inertia about a fore-and-aft axis is found by piecemeal[8] integration to be 0.1138. Thus

[8] That is, the section area is divided in small rectangles, and the area of each rectangle is multiplied by the square of its distance from the axis of the section. The sum of the products is the moment of inertia.

the outer strut, which is 1⅜ inches thick, has the moment of inertia $0.113 \times (1\frac{3}{8})^4 = 0.416$, while the inner strut, which is 1⅞ inches thick, has the moment of inertia $0.1138 \times (1\frac{7}{8})^4 = 1.41$. Substituting these values in Euler's formula for ultimate strength, $P = \pi^2 EI/l^2$, in which $\pi^2 = 10$, $E = 1{,}600{,}000$, l = strut length = 80.75 inches, and I is the moment of inertia of the strut section, there results $P = 1021$ pounds for the outer strut, $P = 3460$ for the inner one. Dividing these strut strengths by the actual compressions they bear, as shown in the stress diagrams and also in Table II, the corresponding factors of safety are obtained.

It gives me pleasure to acknowledge the kind service of Mr. Henry Kleckler and Mr. A. V. Verville in making the computations and drawings included in this paper.

Talc as a Lubricant. F. THALBERG. (*Chem. Zeit.*, xxviii, 711.)—Talc does not behave like graphite on treatment with tannin solutions, but may be brought into a finer molecular state by heating with ammonium carbonate, or by several hours' exposure to a current of dry ammonia. Afterward talc is dried *in vacuo*, since heating causes the particles to agglomerate again. The treated material forms fine suspensions in water which are very difficult to filter, and subsides exceedingly slowly in lubricating oils of medium density. When once suspended in a neutral oil no subsidence of the talc occurs on heating. The change in the character of the talc is attributed to the absorption of a minute quantity of ammonia. From 40 to 60 per cent. of ordinary talc may be introduced into heavy mineral oil, provided that the oil be added to the talc and not the reverse.

Weighting of Silk with Substitutes for Tin. E. STERN. (*Z. Angew. Chem.*, xxvii, 357.)—The earths of monazite sand, as well as titanium and zirconium compounds, could not be used successfully by themselves as substitutes for tin salt, yet satisfactory results can be obtained when used in conjunction with tin. It is suggested that substances analogous in constitution to silk fibroin would be preferable.

Nickel-plated Aluminum. E. TASSILY. (*Rév. Mét.*, xi, 670.)—An adherent nickel deposit on aluminum is easily obtained by Canac's process (English patent 24,019 of 1911). The aluminum is treated with boiling potassium carbonate solution, then brushed with milk of lime, and immersed for a few minutes in a 0.2 per cent. solution of potassium cyanide and in a solution of 1 gramme

of iron in 1 litre of hydrochloric acid (1 : 1) until it acquires a moiré appearance. The nickel is deposited as usual, *e.g.*, from a bath containing 50 grammes of nickel chloride and 20 grammes of boric acid per litre. The addition of iron to the last preparing solution is essential; a minute deposit of iron (0.25 to 0.5 gramme per square metre) was found on the aluminum, and microscopical examination of the surface showed a cellular structure. The iron appears to form a network of microscopic galvanic couples, which produces a rough surface. This accounts for the strong adhesion of the deposit, which can not be detached without also tearing off aluminum particles.

The Manufacture of Electrolytic Alkali. DISCUSSION. (*Soc. Chem. Ind. Journ.*, xxxii, 993.)—This discussion tended to show that several processes were technically satisfactory. The Finlay cell produces 8 per cent. caustic liquor at a voltage not exceeding 3, and with a cathodic current efficiency of 98 to 99 per cent. The Billiter-Siemens cell was also satisfactory. The main point is the price at which power can be purchased or generated. Some speakers thought that the figures obtained by the best municipal authorities represented the irreducible minimum, while others asserted that even a small private plant with 100 per cent. load factor, such as would be the case with an electrolytic alkali plant, could be worked much cheaper, and could generate power at a price of 0.1d. per unit. Particulars were given of working results obtained with cells of the rocking Castner type. The total loss of mercury should be less than 2 per cent. per annum, and profits could be made if power did not cost more than 0.3d. per unit.

Prevention of Cementation by Metallic Deposits. L. GUILLET and V. BERNARD. (*Bull. Soc. d'Encour.*, cxxi, 588.)—A layer of electrolytically deposited copper, 0.02 to 0.04 mm. thick, is stated to be the most advantageous coating agent for protecting portions of an article from cementation. Nickel can not be used instead of copper, as it is permeable to carbon monoxide. *Diffusion of Solid Metals.*—When the following pairs of metals were heated together, with their surfaces in intimate contact to a temperature below the fusion point of the lowest-melting metal, diffusion of one metal into another was observed: Iron-aluminum; iron-copper; copper-nickel; copper-bronze; copper-tin; copper-brass; copper-zinc.

Bactericidal Power of Mercuric Iodide. H. STASSANO and M. GOMPEL. (*Comptes Rendus*, clviii, 1716.)—Comparative experiments with mercuric chloride, iodide, cyanide, and benzoate, carried out with very dilute solutions (N/1000 to N/500,000) in order to avoid the use of double salts, indicate that mercuric iodide is a much more powerful bactericide than the other salts and is about ten times as active as the chloride.

THE ULTRA-VIOLET RAYS AND THEIR APPLICATION FOR THE STERILIZATION OF WATER.*

BY

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We have seen within the last years the creation of a new industry,—namely, the application of ultra-violet rays for the biologic purification of water. I think it of interest to lay before you the basis on which this industry is founded.

Almost every source of light produces with the visible rays some wave-lengths shorter than those which are perceptible to our eyes. These radiations are known as ultra-violet rays. They begin at about .3969μ and have been observed down to wave-lengths of about .1000μ. I may say at this point that some observers have been able to get light sensation from wave-lengths shorter than .3969μ. This, however, is explained by the fact that the crystalline of our eyes becomes fluorescent under the influence of such ultra-violet radiations, and produces thereby the impression of gray on the retina; that is to say, we do not see the ultra-violet light, but we see the fluorescence of our own crystalline.

This production of *fluorescence* is one of the characteristics of ultra-violet radiations. It is very noticeable with many of the fluorescent dyestuffs and organic compounds.

Another physical quality of ultra-violet radiations is their ability to *ionize* the air, which manifests itself by the automatic discharge of a condenser under ultra-violet light.

More distinct are the *chemical reactions* under ultra-violet light, the most noticeable being the generation of ozone and nitrous acid, which produces the characteristic odor of spark and arc discharges. Almost any chemical reaction which is influenced by the presence of light is much more influenced by

*Presented at the meeting of the Section of Physics and Chemistry held Thursday, October 1, 1914.

ultra-violet light. I mention only the decomposition of silver salts.

The typical characteristic of ultra-violet light (which is practically confined to these wave-lengths, with the exclusion of the visible wave-lengths) is the *bactericidal* power or, to use a more general expression, the " abiotic power " of these radiations. That the visible rays have practically no abiotic (but even philobiotic) power is probably due to the fact that living beings have adapted themselves to the rays which they generally receive from the sun, while they are not resistant against rays which they do not normally receive. In the same way they will withstand certain temperatures they are accustomed to, but will suffer from higher temperatures.

As said before, some wave-lengths are favorable to life. I refer to the chlorophyll production for which light is necessary. It may be seen, therefore, that exact information on the favorable or unfavorable influence of light on life can be obtained only by separating the visible from the invisible rays. There is, unfortunately, no source of light known which produces only ultra-violet radiation without producing at the same time visible wave-lengths.

The first work in this line is due to Downs and Blunt, who studied the action of sunlight on different organisms and organic tissues. We owe some further results to Geissler, Chmelewski, Bruckner, Duclaux, Ledoux, and particularly to Marshall Ward, to whom we owe the first biologic spectrum analysis. He threw the spectrum on an infected agar plate, with the result that the parts of the plate which were exposed to the violet end of the spectrum did not show any growth of colonies, while the parts which were exposed to the red end of the spectrum developed growth. He found that the abiotic power of ultra-violet light was the same in air as in vacuum. Ward sterilized Thames water by exposing it to ultra-violet light.

However, we owe to Finsen and his school the first real analysis of the abiotic phenomena occurring under the influence of ultra-violet light. His work resulted in the therapeutic use of the ultra-violet ray lamps. Finsen found that the abiotic reaction became very powerful as soon as one reached wave-lengths shorter than .3μ; that is to say, as soon as wave-lengths

appeared shorter than those contained in the sun's rays on the surface of the globe. Finsen proved that abiotic action was independent of the presence of oxygen. He also studied the powerful absorption of ultra-violet by colloidal solutions. His pupil, Bang, determined the relative resistivities of different germs to this light. He also found that young cultures were less resistant than older ones. Some of Finsen's pupils proposed the adoption of ultra-violet light for the sterilization of liquids such as milk, etc. In short, we may say that since Finsen's time the ground was well prepared for the industrial application of ultra-violet light for the biologic purification of different substances.

These studies were taken up again in 1909, particularly in France, by Courmont, Nogier, Vallet, and others. Very elaborate researches were carried on in the Physiological Laboratory of the Sorbonne University by Henri, Helbronner, and von Recklinghausen, which work has resulted in considerable technical application.

The history of this industrial use of the ultra-violet rays is intimately linked with the development of means for producing these ultra-violet rays. It is therefore of interest to go somewhat deeper in the subject of different sources which produce these rays.

The great source of ultra-violet radiations and "the cheapest disinfectant known," as Duclaux puts it, is the *sun*. Rivers and lakes are freed from a great part of their bacterial contents by the bactericidal power contained in the sun's rays.

The spectrum of the sun is in itself not very rich in ultra-violet rays of short wave-lengths, the shortest being .29μ. However, in high altitudes where the light of the sun has to pierce a smaller layer of air it is much richer in ultra-violet, as may be seen from the fact that sunburns are quickly produced if we expose ourselves in high altitudes—mountains or balloons—to the sun.

Small amounts of ultra-violet are produced by practically all artificial light sources. Electric discharges, and particularly the discharges between volatilizable metals,—that is to say, spark-gaps and arcs between metal electrodes,—are very powerful producers of ultra-violet radiations. Finsen himself used an arc between iron electrodes after having found that such an arc is about fifty times as powerful as an arc of the same wattage be-

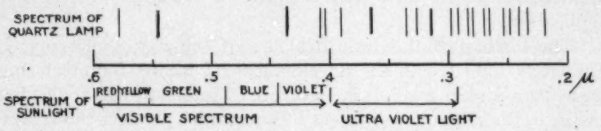
tween carbon electrodes. Electrically speaking, the arcs between metal electrodes are more stable and easier to produce than spark discharges, because the apparatus is simple, as it consists merely of the electrodes and the necessary ballast resistances.

Powerful spark discharges are difficult to produce; the high tension accessories from them are cumbersome and apt to get out of order; besides, all large-capacity sparks have the disagreeable feature of producing a fearful noise, reminding one of a machine gun.

Arcs as well as sparks are accompanied by disintegration of the metal and the production of metal fumes. These have to be removed from the sphere of discharge so as to prevent obturation.

The disintegrated metal has to be replaced after being volatilized by the heat of the arc or spark discharge. The replacement

FIG. 1.



Spectrum of quartz lamp and of sunlight.

is easiest if the disintegrated metal condenses easily and can be made to flow back to the electrode containers. This is the case if *mercury* is chosen as electrode for the discharge. Means have to be provided to hold the vapors of the disintegrated mercury together and prevent their contact with the air; that is to say, the arc has to be enclosed. The material into which the arc is enclosed has to be transparent to the discharge of ultra-violet rays. The only industrial material filling this demand is rock crystal in the natural or fused state, which we commonly call fused quartz (Fig. 1).

The reason why Finsen's research would not yield immediate technical application was the fact that this mercury quartz lamp did not exist at his time. The mercury arc, although one of the first powerful arcs invented (Way, 1860), became a commercial device only some thirteen years ago, when Cooper-Hewitt's research produced the now well-known Cooper-Hewitt lamp, where the mercury electrodes and the discharge path were enclosed in

glass. Schattner and chiefly Kuech and Heræus, and later on the Westinghouse-Cooper-Hewitt Company, built these lamps out of quartz.

Their reason for using this material in preference to glass was originally not so much on account of the permeability of the quartz for ultra-violet rays, but because the quartz, having a melting point of about 1700° C., allowed them to run the lamps at a greater temperature than glass lamps. Thus the lamps became very much shorter and easier to handle mechanically than the cumbersome glass tubes. As quartz allows, roughly, 1000 times as much of the ultra-violet to pass through as glass, we have, naturally, to use exclusively quartz-enclosed mercury lamps for the industrial production of the desired ultra-violet rays.

The construction of the mercury quartz lamps presents one

FIG. 2.

Quartz lamp seals.

difficulty which we do not have in the case of the glass lamps. In the latter the current is led into the lamp through platinum wires which are fused into the walls of the tube, this being easy to do, as the expansion coefficients of glass and platinum are very much alike, and it is therefore not difficult to render such a platinum glass seal tight. Quartz, however, has an expansion coefficient which is practically zero, and there exists no metal of similar characteristic at the temperature where quartz is soft enough to mould it into a seal. We are therefore unable to produce in this simple way the current leads.

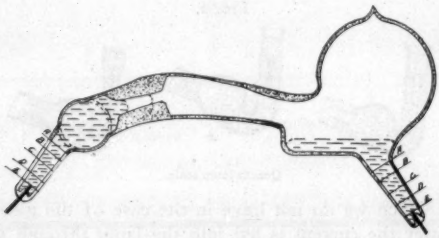
Several ways have been proposed to overcome this difficulty; the first and most commonly used is (Fig. 2A) to grind a stopper into the quartz tube, choosing as material for this, a metal which has as low a temperature coefficient as possible in the range of temperature to which such a seal is normally exposed; that is to say, between room temperature and about 300° C. The metal composition used for this purpose is Guillaume's nickel steel alloy, "In-

var." Its expansion coefficient is practically zero. However, if heated above the temperature of 300° C., the expansion coefficient becomes highly positive. It is therefore clear that this is one important reason why Invar can not be sealed into quartz at the latter's softening point. After grinding the Invar stopper into the lamp, mercury must be placed on top of the seal so as to prevent the air from leaking into the lamp.

Another way which was used for some time was the double cone seal made of platinum (Fig. 2B), which is fused into a restriction in the quartz tube. This seal also has to be covered with mercury so as to make it air tight.

Some other metals, such as tungsten and molybdenum, can be sealed into quartz (Fig. 2C). In cooling, however, they will

FIG. 3.



110-volt mercury vapor quartz lamp.

contract, and such a seal will leak. This can be prevented by mercury sealing, as described above for the Invar seal.

Keyes and Kraus have made seals for quartz lamps (Fig. 3) by using an ordinary platinum glass seal which was fastened to the quartz tube *A* by means of several intermediate steps, *B, C, D, E,* of different glasses of a gradually decreasing temperature coefficient. The General Electric Company is using a similar seal.

To run efficiently and with a small percentage of ballast resistance, we found it necessary to maintain the vapor inside the quartz lamp below saturation. To obtain this, one must give the lamp the proper dimensions and provide means for considerable cooling of the electrodes, either by giving the electrode containers rather a large radiating surface or by artificially cooling the same.

In the usual types of quartz lamps for efficient ultra-violet ray productions both electrodes are of mercury.

As the energy consumptions at the two poles are different, migration of the mercury takes place towards the cooler pole. This is counteracted by properly proportioning the two electrode containers. Besides, we equip the negative pole with a conic restriction. If this cone becomes too full of mercury the electrode surface is restricted and its temperature is thereby raised. Increased evaporation thus results, which causes the mercury level in the cone to be lowered; that is to say, the level in this electrode maintains itself automatically (Fig. 3).

Many trials have been made to replace the mercury by alloys which would yield more ultra-violet. It seems doubtful, however, whether this can be accomplished industrially, as difficulties are experienced with the attack on the quartz and the coating of the inside of the luminous tube. I found very strange forms of attack on the quartz when metals like copper are added to the mercury. These metals segregate themselves from the mercury in the negative electrode and penetrate deep into the wall of the reinforced quartz, producing thereby radical fissures of the walls. Inside these fissures the foreign metal deposits itself in thin sheets. In short, it seems best to avoid the contact of the arc with any metal but mercury.

Quartz, unfortunately, absorbs all wave-lengths below .2μ. As these are very strongly abiotic, we thought it of interest to study how far naked spark discharges—aluminum and cadmium—would be applicable, as their spectrum is rich in short wave-lengths. Considering, however, that air absorbs in thin layers practically everything below .1815μ, it is somewhat doubtful whether it would be practical to construct apparatus where we could use these shorter wave-lengths to advantage in sterilizing water unless the sparks are produced under the water, as Kowalsky proposed some time ago. However, there is always the disadvantage of demanding an elaborate high-tension arrangement for the production of the sparks, and no means have yet been found to avoid the terrific noise produced by such sparks.

We need consider, therefore, only the *mercury quartz lamp* as an industrial source of ultra-violet, and the research and technical work done with them for the purpose of industrial sterilization.

As I had the pleasure of being connected with most of the

work done at the Sorbonne University in this line, I will refer to this work and the conclusions that we arrived at.*

To start with, we had to determine whether the ultra-violet rays produced by a quartz lamp would yield enough abiotic power to sterilize water. In the majority of cases we found that an exposure of a fraction of a second (in some cases one-twentieth) close to the lamp would result in the death of the microbes. As might be expected, we found that the abiotic power diminished about as the square of the distance from the lamp. We then determined the relative resistivity of different germs to the light, and found that they do not vary as much in their resistivity against ultra-violet as in their resistivity against heat and disinfectants. For instance, spores are often twenty times as resistant as the unprotected forms of germs against chemicals, while against ultra-violet light they are only 1.5 to 5 times as resistant as ordinary unprotected water bacteria.

Fig. 4 shows a comparison of the resistivities of different types of germs; in each case cultures were made under similar conditions and the free germs put into clear water, care being taken to avoid clumps of bacteria and presence of the culture medium, for otherwise the germs would have been protected more or less against the rays.

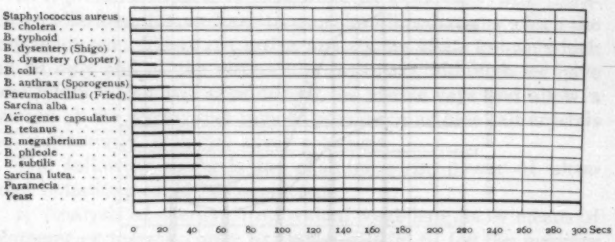
It has sometimes been thought that the bactericidal action of the ultra-violet rays was due to a small amount of hydrogen per-

* Publications by Henri, Helbronner, and von Recklinghausen: *Comptes rendus de l'Académie des sciences,* January 3, 1910; April 11, 1910; October 17, 1910; February 28, 1910; July 24, 1911; August 14, 1911; July 22, 1912; August 5, 1912; August 19, 1912; October 28, 1912.
La Presse Medicale, January 12, 1910.
Le Génie Civil, October, 1910.
The Association of Water Engineers, July, 1911.
Congresso Internazionale delle Applicazione Elettriche, Torino, 1911.
Journal de Physiologie et de Pathologie générale, November, 1911.
Société de Chimie-Physique, June 12, 1912; June 26, 1912.
Comptes rendus de la Société de Biologie, June 15, 1912.
Journal für Gasbeleuchtung und Wasserversorgung, October 26, 1912.
Société de Médecine Publique et de Génie Sanitaire, December, 1912.
Bulletin de la Société internationale des Electriciens, March, 1913.
Electrical World, July 26, 1913.
Engineering Record, August 2, 1913.
Engineering News, August 21, 1913.
Journal of the American Water Works Association, September, 1914.

oxide which indeed forms itself by the exposure of water to the ultra-violet rays. However, this formation is so minute that it is barely noticeable after ten hours of exposure of the water, and we can positively state that the bactericidal effect is not due to the action of a so-formed disinfectant, because the amount of hydrogen peroxide which can possibly form itself during the time and at a distance which is necessary to kill the microbes is only about one fifteen-thousandth of the amount which would be necessary to act as a successful disinfectant.

The abiotic action is independent of the temperature between zero and 55°. We also found it to be the same in clearly frozen

FIG. 4.



Seconds necessary to kill different types of germs at 200 millimetres from a quartz lamp burning at 66 volts, 3.5 ampères.

ice as in water. It is surely not probable that by the action of the rays during the short time necessary to kill the bacteria the entire bacteria should be chemically changed, coagulated or otherwise modified. It is more probable that some ferment or similar product contained in the cell is modified by the rays and thereby the system of the cell is poisoned.

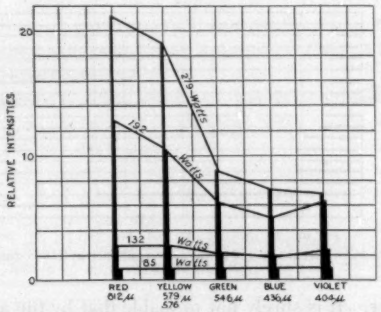
As the mercury vapor lamp can be run at different temperatures by increasing or decreasing the voltage on the electrodes, it was of interest to study the influence of the electric characteristic of the lamp on its abiotic power. As will be seen hereafter, we found that this power increases greatly with increasing lamp temperature. This is somewhat surprising, as the red part of the spectrum increases in power much more than the violet end with increasing lamp temperature. We found this from the following experiment (Fig. 5). We took an ordinary 110-volt quartz

lamp and made a spectrophometric analysis of the five principal colors composing the visible light of these lamps. As the table shows, an increase in watts,—that is to say, of temperature,—produced a much greater increase of the red and yellow than of the blue and violet. As will be seen later on, the ultra-violet end of the spectrum increases about like the red end; that is to say, it increases in power much more than the blue and violet visible rays.

These experiments led us to go somewhat more fully into the question of measuring the ultra-violet candle-power of our lamps, and we come to the following considerations:

The candle-power standard for ordinary light is not a physical

FIG. 5.



standard, but a physiological one, being the effect on the eye of the sum of the visible wave-lengths emitted by a defined source of light; that is to say, a standard candle.

The eye not being sensible to ultra-violet, we consider only the total visible energy sent out by this standard lamp. If we want to define a standard of *ultra-violet* light, we must either define in energy units the power of each individual wave-length or we must imitate our method of defining the standard of ordinary light and define our standard of ultra-violet as the unit total effect produced by the ultra-violet rays. However, as effects on chemical reactions and perhaps biologic reactions may be influenced in a different and irregular way, by different wave-lengths, it is probable that the sum of such effects may be identical if one kind of reaction is chosen, and may not be identical if

another kind of reaction is chosen. The only true way of defining the power of the rays is by the analysis of the spectrum and the determination of the energy sent out by each wave-length. This is evidently right from the physical point of view, but inconvenient in practice. We therefore thought better to choose as a unit some value of the particular reaction which concerns the work in hand. If we want to follow chemical reactions under the ultra-violet light, we choose arbitrarily as a unit one in which the desired reaction takes place in a defined way after a unit period of exposure to all the rays of the lamp. We may therefore say that for every type of reaction under the light we have to define a new unit of activity.

In a practical way it is impossible to work only with ultra-violet radiations, for we have to consider all radiations which the lamp sends out. There are, unfortunately, no filters known which will let *only* and *all* the ultra-violet rays pass, although we have some filters which will take out all the visible rays and allow a fraction of the ultra-violet rays to pass, such as blue salt crystals and, particularly, colloidal silver solutions.

The following methods for examining the power of ultra-violet radiations could be considered:

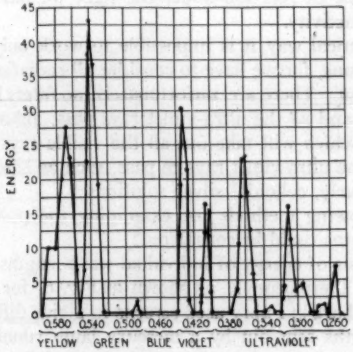
1. Analysis of energy of individual wave-lengths by means of bolometer or thermocouple, as shown in Fig. 6, for the mercury lamp (Ladenburg): Fabry used screens to divide different groups of wave-lengths sent out by a mercury lamp running at a low temperature, and found by this method the following distribution of energy: 93.7 per cent. in the infra-red, 3.6 per cent. in the visible light, 2.7 per cent. in the ultra-violet light.

2. Ultra-violet light falling on a condenser will ionize the air, and this will be followed by a discharge of the condenser. So far as I know, this has not as yet been used for analyzing ultra-violet spectra.

3. Photochemical reactions were chosen. Usually they are strongly influenced by ultra-violet light. For instance: the blackening of photographic paper goes on four times more quickly under a naked quartz lamp than under the same lamp with glass interposed. We can build a sensitometer of paper, using this blackening as indication of the power of the light. If we expose the different wave-lengths separately, that is to say, in a spectrophotographic apparatus, to the photographic plate we must con-

sider that we can thereby compare only the strength of individual lines of equal wave-lengths coming from different sources by comparing the time of exposure necessary to obtain equally strong pictures of such lines. With chemical reaction, like the exposure of f. i. photographic paper (nitrate of silver) to all the rays of a lamp, it is fairly easy to define a standard unit of effect, as the same chemicals will be equally sensible to the same amount of light. If, however, we choose a unit of bacterial reaction, we find that our reaction will depend very much on the *quality* of the

FIG. 6.



bacteria we submit to the light. Although produced under identical conditions, the same kind of microbes vary very much in their resistivity against light. This means that it will be impossible to get sufficiently constant abiotic results upon which to base a unit reaction. We must therefore create a laboratory standard of ultra-violet light and determine with this the sensitivity of our biologic agent, our culture of microbes. After having defined this resistivity we can use the same culture to define the power of an unknown lamp which we want to determine.

The abiotic reaction which we choose as most convenient to handle was the exposure necessary to kill paramecias, these being similar to water-bacteria and easy to cultivate and to observe directly under the microscope, as they have a very violent motion when living and, naturally, no motion when dead. We expose a

drop of such culture at a defined distance from the lamp, and count the seconds necessary to render them motionless. We obtain thereby comparative figures of the abiotic power of our standard lamp and of the unknown lamp.

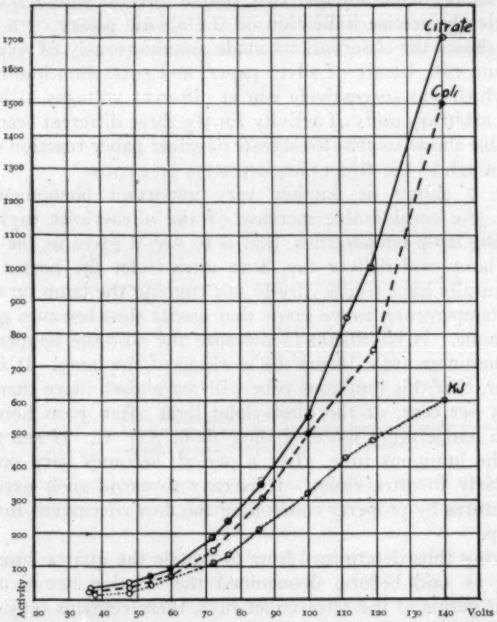
As the photographic paper method is much simpler to handle, we compared the figures obtained therewith with the abiotic reaction so as to see whether this simple method would not give a sufficiently precise indication of the abiotic power of a lamp. Fig. 7 shows the observations made simultaneously of exposing bacterium coli, citrate of silver paper, and potassium iodide to a lamp which was successively run at different voltages, using, of course, arbitrary units of activity for the three different reactions. This table shows us that the citrate of silver paper reaction comes close enough to the direct measurements on germs.

Fig. 7 shows us another very important phenomenon,—namely, the considerable increase of the ultra-violet rays with increasing lamp temperature; that is to say, it gives us the proof that a lamp will deliver the more ultra-violet the hotter it is. We naturally have to use care in not running the lamp up to too high a temperature, as we know that quartz thus becomes gradually opaque. It is difficult to measure the absolute temperature of the luminous tube during the working of the lamp. It seems, however, that this luminous tube will not absorb more than perhaps 25 per cent. of the ultra-violet light after 3000 hours, if run at a temperature not exceeding about 700° C. If run above 800°, the luminous tube, after a period, becomes very opaque, particularly to ultra-violet. It is easy to avoid such excessive temperatures by properly controlling the flow of current through the lamp.

Having thus determined how to handle the quartz lamp and having, as said before, determined the relative resistivity of different germs to the ultra-violet rays, there remains only to be determined the principle on which to design proper apparatus for leading the water at the right speed through a zone which is illuminated by an efficient lamp. The following point had to be considered, in designing the apparatus: Water is practically as transparent as air to ultra-violet rays, provided it is clear; that is to say, in many cases it will first have to be filtered to free it from suspended matter, and, if possible, also from colloidal matter, which would otherwise retard the passage of the rays.

Careful observation of well-filtered water will, however, nearly always reveal the presence of a small amount of suspended matter of a large enough size to allow microbes to be protected against the rays. To sterilize such water with safety, we found it useful to agitate it while passing through the illuminated zone,

FIG. 7.

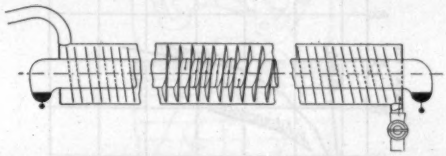


Comparative measure of ultra-violet activity of 220-volt quartz lamp burning at different voltages by three methods: (*a*) Decomposition of citrate of silver; (*b*) decomposition of potassium iodide, (*c*) annihilation of bacterium coli.

and to expose it several times to the light of the same lamp or to several lamps in succession; thus small suspended matter is exposed on all sides to the action of the light. The automatic stirring up is best accomplished by a proper arrangement of baffle plates in the apparatus, which are so placed as to create a minimum of shadows.

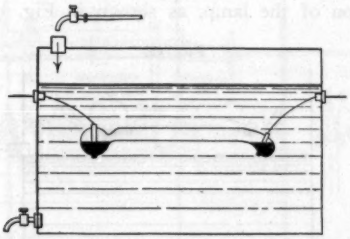
The first mercury lamp water sterilizer was invented by De Mare in 1906, and is shown in Fig. 8. Some years later Courmont and Nogier placed a mercury lamp in a barrel of water, submerging the lamp completely into the water (Fig. 9). This seemed at first a most efficient way, because all the rays from the lamp entered the water. After examining the ultra-violet

FIG. 8.



efficiency of such a lamp burning directly in the water, we found it, however, to be very much impaired by the cooling effect of the water. Fig. 10 shows the activities measured of the same lamp in the water in the open air and enclosed in a casing (which decreased the radiation from the lamp and thereby increased its temperature). Apart from this, deposits form easily on lamps

FIG. 9.

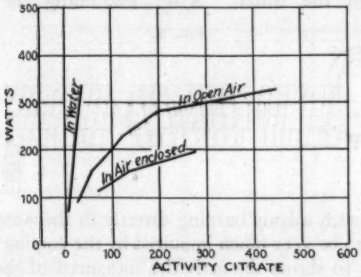


which are in direct contact with the water, rendering the luminous tube thereby opaque. Our first experiments with running water were made in an apparatus shown in Fig. 11, and from this we developed the apparatus shown in Fig. 12, which contained the stirring baffles described above. Our first experiments on a large scale were made with a canal (Fig. 13), equipped with several lamps placed on floats close to the surface of the water.

A small sterilizer is shown in Fig. 14. Its characteristic part

is the lamp. Its electrode containers are cooled by the water of the sterilizer itself. The luminous tube, however, is above the water. Such a burner represents the simplest type of mercury vapor quartz lamp. In all these types only the light sent down-

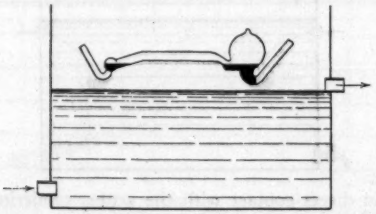
FIG. 10.



wards from the lamp enters the water, as it is almost impossible to reflect ultra-violet rays.

For the purpose of using all the rays of the lamp and eliminating the cooling effect of the water on the luminous tube caused by the submersion of the lamp, as shown in Fig. 9, the Quartz

FIG. 11.



Lampen Gesellschaft sealed a quartz jacket over the lamp, as Fig. 15 shows. However, these lamps were difficult to manufacture. We therefore constructed the apparatus shown in Fig. 15, where the sterilizing tank is equipped with a lamp box to which quartz windows are fitted. The lamp can easily be inserted into this box, and its light shines through the windows into the water, the

FIG. 12.

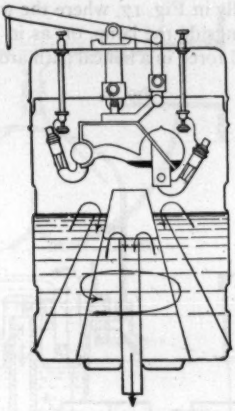
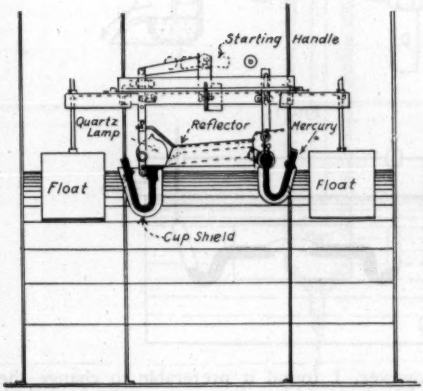
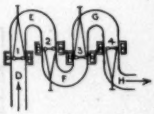


FIG. 13.





lamp itself being protected from the cooling effect of the water by the box.

Another way of using all the light emitted by a lamp without

allowing the lamp to be touched by the water and cooled thereby is shown schematically in Fig. 17, where the water flows in a concentric waterfall alongside the lamp, or, as in Fig. 18, where it is forced by centrifugal force in a helical path around the lamp.

FIG. 14.

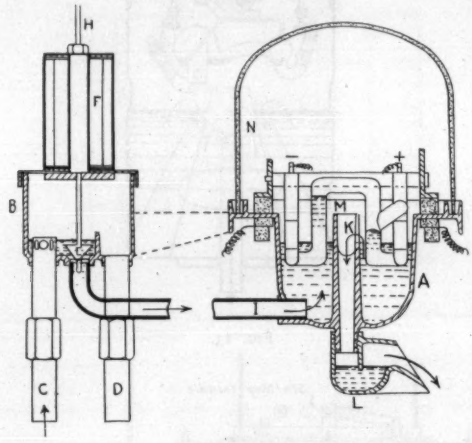
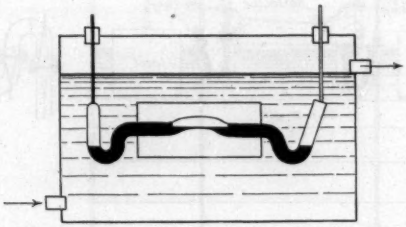


FIG. 15.



In the end, however, I found it preferable to change the shape of the lamp,—namely, by bending the luminous tube in a closed U shape, with the cumbersome electrodes on one side only. From the shape so obtained I have called these "Pistol" lamps. They are shown in Fig. 19. The luminous part of these lamps

FIG. 16.

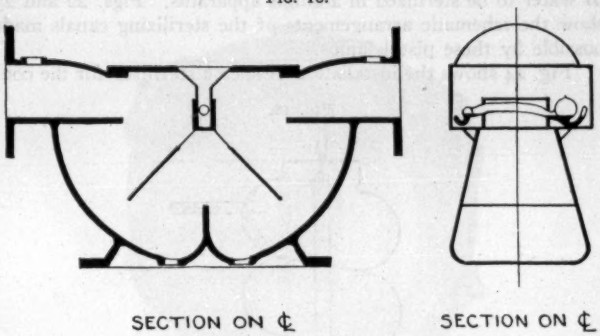
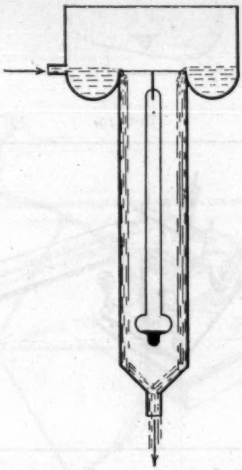


FIG. 17.



is inserted into a quartz tube which is fitted hermetically to the walls of the sterilizing tank. Figs. 20 and 21 show such apparatus. This arrangement furnishes a simple way of placing several lamps into the same tank, allowing thereby large amounts

of water to be sterilized in a single apparatus. Figs. 22 and 23 show the schematic arrangements of the sterilizing canals made possible by these pistol lamps.

Fig. 24 shows the installation of such a sterilizer for the con-

FIG. 18.

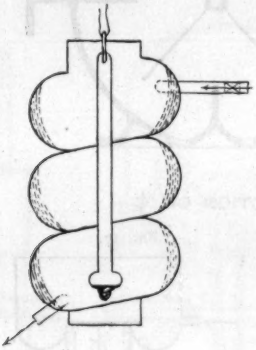
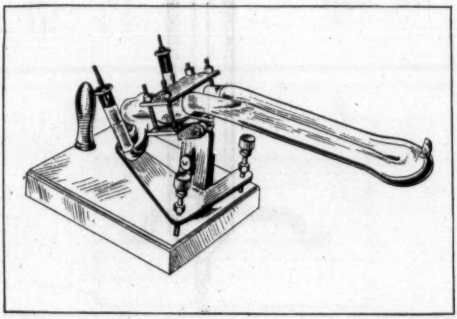


FIG. 19.



tinuous purification of the water for a large swimming tank, which is subject to continual contamination by the bathers. Fig. 25 shows a large city installation using a ten-lamp canal in the city of Luneville, France.

It is interesting to note that the hygienic results obtained with

FIG. 20.

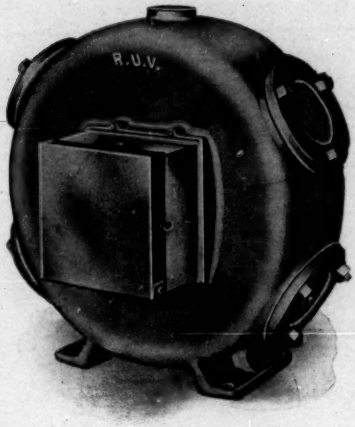
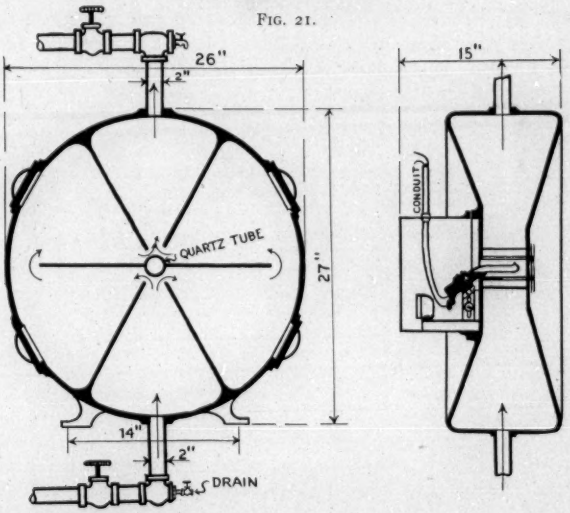
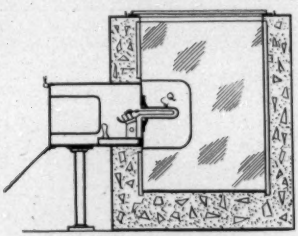


FIG. 21.



this Luneville plant are extremely satisfactory and prove better than any tests the importance of this system, as typhoid fever has been practically eliminated from this town since the introduction of this sterilizing system. Several large plants of the same type of apparatus are under construction.

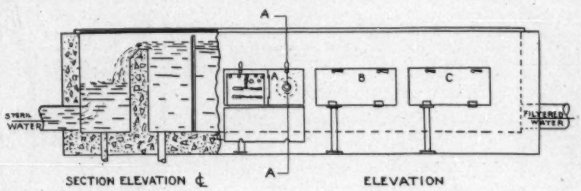
FIG. 22.



SECTION A-A

If the water is used for drinking purposes, one can easily run the sterilizer so as to remove surely all pathogenic bacteria. A very short exposure of a minute or two in the large city water sterilizers is sufficient for this, provided filtration has previously removed the matter suspended in the water. The energy con-

FIG. 23.



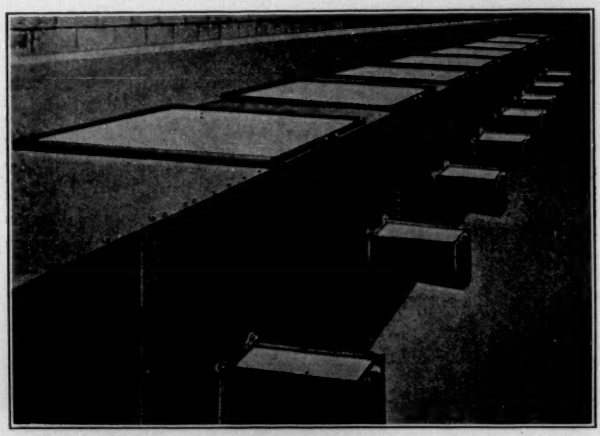
sumption in such cases is extremely small and varies between 50 and 130 kilowatt-hours per million gallons of water, allowing for very large safety coefficients.

If the water is used, for instance, for surgical purposes where absolute sterility is of importance, the smaller apparatus is used, and the exposure is so arranged that surely no microbes will

FIG. 24.

Swimming pool of the new West Side Y. M. C. A., showing the R. U. V. installation.

FIG. 25.



Sterilization plant in the city water works, Luneville (France).

escape the abiotic action of the rays. In a clear water a few seconds' exposure in such apparatus will completely annihilate germ contents of thousands of germs per cubic centimetre.

The transparency of clear water to ultra-violet rays renders the sterilization of water, even on a larger scale, very simple and, as experience has proven, perfectly practical.

If we now come to the sterilization of opaque bodies, we find that the problem is very much more difficult. The penetrating power of ultra-violet through opaque bodies is in every case much less than the penetrating power of visible light. If we try, therefore, to sterilize opaque bodies, we must submit them in such thin layers that the light will penetrate to the far layer of such a film, so that even this is sterilized and cannot reinfect the part of the film which is nearer the lamp. Many experiments have been made by ourselves and others in attempts to sterilize milk. Some of the experiments have been only partly successful because the milk was exposed in too thick a layer. It is, however, perfectly feasible to obtain successful sterilization if one uses the precaution to spread out the milk thin enough, and particularly if one takes very fresh milk,—that is to say, milk containing young microbes.

The mechanical difficulties of obtaining a thin film have so far prevented the industrial application of the ultra-violet rays for the sterilization of milk. I believe, however, that it will soon be attained.

Ultra-violet rays not only kill bacteria but they also destroy toxines, as many laboratory experiments have proven. This fact seems to give an explanation of the healing effect of the light bath, the effect of which was always somewhat mysterious. It seems to me quite possible that the blood is exposed right near the skin during its circulation from the artery to the vein system to the ultra-violet light and gets more or less sterilized thereby and freed of its toxine contents. I understand that lately experiments with tuberculosis patients who were exposed to quartz lamps have given excellent results, widening thus the field of the application of the ultra-violet rays.

Ultra-violet rays have been used for many reactions, such as bleaching and the production of chemical compounds. None, however, have attained the industrial application that the sterilization of water has accomplished.

NOTES ON CATENARY CONSTRUCTION OF NEW YORK, WESTCHESTER AND BOSTON RAILWAY.*

BY

SIDNEY WITHINGTON,

Assistant Engineer, New York, New Haven and Hartford Railroad.

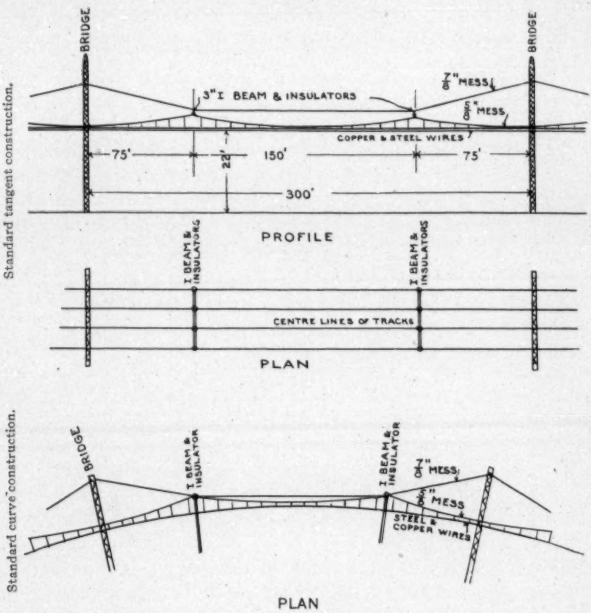
THE problem of distribution of high-voltage electric power (either alternating or direct current) to trains moving at very high speeds resolves itself into locating an aërial wire (or two wires for three-phase power) out of reach of persons walking on or crossing the track, and in such a position that it may be easily reached at all points by the collecting apparatus of the locomotive. Vertical variations in location of the wire with respect to the track, if they are necessary (as at highway bridges, etc.), should be gradual, so that the collecting devices will suffer as few sudden changes in position as possible, and so that the pressure of the shoe against the wire will not have to be increased to prevent the shoe being thrown away from the wire, causing arcing. There should be as few "hard" spots in the wire as possible; that is, the pressure of the collecting devices should displace the wire at the point of contact everywhere along the line in equal amount. Spots where the support of the wire is too rigid will cause shocks, and the contact wire will become hard and eventually break.

The contact system of the New York, Westchester and Boston Railway, installed about 1912, consists of a 4/0 grooved steel "contact" wire of standard section, supported approximately every ten feet by malleable iron clips from a 4/0 grooved copper wire of similar shape, 1¾ inches above it, and in the same vertical plane. This copper, or "trolley," wire is in turn supported from a ⅝-inch steel strand by hangers of variable length, in such a way that it lies in a straight line parallel to the track. The hangers are ½-inch steel rods screwed at each end into malleable iron clamps. On tangents the hangers are located midway between the clips supporting the contact wire, and on curves the hangers and these clips are combined, the flexibility being obtained by the inclination of the hangers from a vertical plane normal to the track. The

* Communicated by the Author.

hangers are clamped to the 5/8-inch strand and to the copper wire on tangents, and the clips supporting the steel contact wire from the copper trolley are tightly fastened to the former and hang loosely from the latter. On curves the hangers are clamped tightly to the messenger and to the steel contact wire, but loosely around the copper.

FIG. 1.

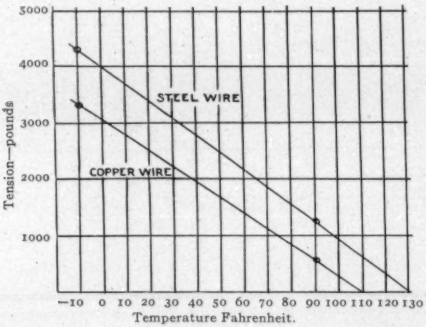


The 5/8-inch messenger or "track messenger" is supported by a suspension insulator from an *I*-beam of standard section, 3 inches x 5½ pounds per foot, located horizontally, normal to the centre line of the tracks, extending over them all and tying the track wires together mechanically. The *I*-beams are located at the quarter points of each span, and are clamped to the 7/8-inch steel strands (one strand over each track). These 7/8-inch or

"main messengers" are grounded, and, besides supporting the catenary system, serve as an addition to the "ground return" for the traction power, and as a protection against lightning. They are supported by structural steel bridges on malleable iron saddles, and are tightly clamped to each bridge by "U" bolts.

The contact wire lies closely parallel to the centre line of the track, both on tangent and curve; that is, there are no sudden bends or corners in the wire, which follows curves smoothly. The normal clearance is 22 feet above the top of the rail, and the steepest grade with respect to the track is 1 per cent. (see Fig. 1).

FIG. 2.



Temperature	Copper	Steel
− 10°	3300 pounds	4300 pounds
+ 30°	2200 pounds	3100 pounds
+ 60°	1400 pounds	2100 pounds
+ 90°	570 pounds	1220 pounds

Stresses in contact and trolley wires.

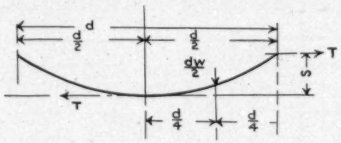
For curves sharper than 4°, pull-off poles were installed midway between the catenary bridges, pulling the 7/8-inch messengers over far enough to relieve the bridges of any stress in excess of that normally produced by a 4° curve, the trolley wires and 5/8-inch messenger being also pulled off so that the curve consisted of a series of 4° arcs. (In two special cases two pull-off poles were provided in each span, located at the end of each of the *I*-beam frames.)

In erecting the system, the 7/8-inch messengers were first pulled out over all tracks and laid in the malleable iron saddles which

had been clamped to the catenary bridges. Then the strands were pulled up to the required tension, as indicated by the sag. The proper sag was obtained for each span by means of a light bamboo pole with a target at the end and with a sliding hook which could be clamped at any desired position on the pole. This pole was hooked on the messenger and the tension was adjusted so the adjacent saddles and target were in a straight line.

When the 7/8-inch strands had all been sagged, the next step was to install the *I*-beam frames and insulators. This was carried out from a large tower car, which was located on one of the centre tracks, and which was provided with collapsible wings for working over the two neighboring tracks, and from a small hand tower car on the fourth track. The insulators and fittings were installed with the *I*-beam frames.

FIG. 3.



The next step was to string the 5/8-inch messenger, which was done by anchoring the end and running out the reel on a flat car, the strand being inserted but not clamped in each insulator as it was passed. Every few hundred feet the strand was pulled to the proper sag and clamped.

The trolley and contact wires were strung simultaneously in the same manner as the 5/8-inch messenger, the wires being temporarily suspended at intervals from the 5/8-inch messenger by pieces of wire of about the same length as the hangers.

The hangers were made up in bundles, or sets, of the proper number and lengths for each span—as laid out from track data in the draughting room—and were installed from the top of a train of tower cars, one complete span (150 feet) at a time. The clips between the copper and steel wires were put on at the same time.

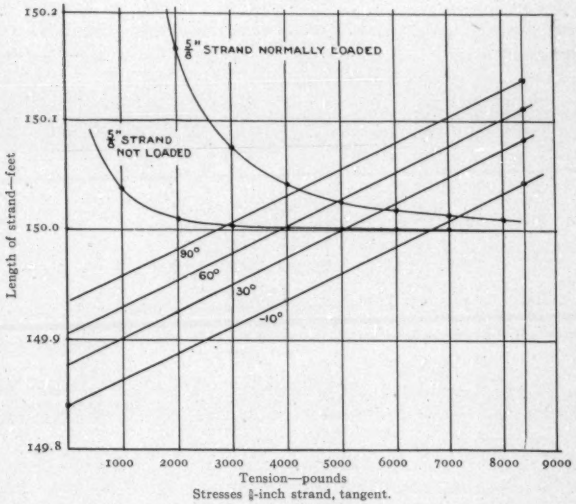
In laying out the hangers, it was arranged that each set should

be located symmetrically to an *I*-beam support, so that changes in length of span or from tangent to curve, or from one degree curve to another, should occur at the "low" point of the catenary. In this way, nothing but complete bundles of standard lengths of hangers were handled by the crew occupying track in the installation of the catenary system.

The data furnished to the field forces were:

1. Location of the saddle castings on the catenary bridges with respect to the track centres (since many of the saddles had to be

FIG. 4.



Stresses ⅝-inch strand, tangent.

installed before the tracks had been laid, the track spacing was also given at each bent location).

2. Proper sag of the main messenger strand for various temperatures without the load of the catenary system upon it.

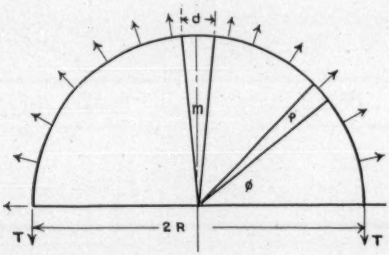
3. Locations of the *I*-beam frames with respect to the steel bridges and the track spacing at each *I*-beam location; also, where special hangers are used between main messenger and *I*-beam, the lengths of such hangers.

4. Proper sag of ⅝-inch strand, not loaded, for the various spans at different temperatures.

5. Appropriate set of hangers for each span, and tension in the trolley wires.

The normal span is 300 feet on tangent tracks and on 1° and 2° curves, 260 feet on 3° curves, and 200 feet on 4° curves, the secondary catenary span being half these figures in each case. The messenger strands are "extra high strength steel," 19-wire, extra heavily galvanized, with an ultimate strength of about 175,000 pounds per square inch. The hard drawn copper grooved wire has an ultimate strength of about 50,000 pounds per square inch, and the steel grooved contact wire about 100,000 pounds per square inch.

FIG. 5.



It was the intention, in laying out the system, to arrange the tensions in the various members so that at 60° F. the stresses in a member should be everywhere the same. If this condition exists at 60° F., equilibrium will not exist between tangents and curves, or between long spans and short spans, at other temperatures, but the difference is not very great, and the catenary bridges are heavy enough to take care of these unbalanced forces.

The conditions of sag, stress, etc., were figured and tabulated for use in the field for tangent and 1°, 2°, 3°, and 4° curves at temperatures of 10° F., 30° F., 60° F., and 90° F. This paper outlines the method of calculation.

The wind load assumed was thirty pounds per square foot of exposed surface, and, in the case of the wires, two-thirds of the projected area of bare wire was assumed as the effective surface.

In assuming a wind and ice load, eight pounds per square foot was taken as the maximum wind load on wires, it being considered that very high winds would blow off the ice or sleet, leaving the wires bare. The ice or sleet load assumed was a coating ½ inch thick on all surfaces (weight of one cubic inch of ice = 0.033 pound).

The modulus of elasticity of steel wire was taken as 29,000,000 pounds per square inch; of steel strand as 26,000,000, and of copper wire as 17,500,006. The coefficient of expansion per degree Fahrenheit was taken as 0.0000064 for steel wire and steel strand and as 0.0000094 for copper wire.

General data of weights, areas, stresses, and loads are given in Table I.

TABLE I.

Material	Ultimate strength, lbs.	Allowed stress, lbs.	Cross-section, sq. in.	Weight in pounds per foot		Wind load in pounds per foot	
				Bare wire	With ice	Bare wire	With ice
4/0 grooved steel.....	16,600	4,300	0.166	0.558	1.158	0.800	0.660
4/0 grooved copper....	8,300	3,300	0.166	0.641	1.241	0.800	0.660
⅝-inch strand.....	45,000	9,000	0.237	0.810	1.506	1.040	0.745
¾-inch strand.....	90,000	18,000	0.498	1.700	2.552	1.460	0.835
Hangers.....	....	....	....	0.177	0.254	0.100	0.100

The following symbols are used in this discussion:

d=Span between supports, feet.
w=Load on wire, pounds per foot.
s=Sag, feet.
T=Tension (total, in wire), pounds.
E=Modulus of elasticity.
C=Cross section, square inches.
R=Radius of curve of track, feet.
A=Mid-ordinate, feet.
F=Horizontal pull of wires normal to centre line of track, pounds.
l=Actual length of material in given span, feet.
a=Coefficient of expansion, ° F.

TENSION IN TROLLEY AND CONTACT WIRES, ON TANGENTS, AT VARIOUS TEMPERATURES.

The trolley and contact wires are rigidly fastened at either end, and so have a constant length at all temperatures. The maximum allowed stress (4300 pounds for the steel wire and 3300 pounds for the copper wire) was assumed as existing at −10° F.; since

the length of the wires is fixed, the stress decreases with rise of temperature.

Assume that a wire is held in such a manner that it is free to elongate or shorten at constant tension, and that the temperature is lowered so the wire shortens a inches; if now the wire is pulled so it elongates a inches and returns to its original length at this lower temperature, this elongation is proportional to the force required to produce it, and the final tension is the same as if the wire were held at constant length during the temperature change.

Change in length due to temperature change $\Delta t°$

$$l = l_0 + l_0(\alpha.\Delta t) \quad \ldots\ldots (1)$$

Elastic change in length due to change in tension ΔT is

$$l = l_0 + \frac{\Delta T.l_0}{C.E} \quad \ldots\ldots (2)$$

Subtracting (2) from (1)

$$0 = l_0.\alpha.\Delta t - \frac{\Delta T.l_0}{C.E}$$

that is,

$$\frac{\Delta T.l_0}{C.E} = l_0.\alpha.\Delta t$$

or

$$\Delta T = C.E.\alpha.\Delta t \quad \ldots\ldots (3)$$

At 90° F. $\Delta t = 100°$ F., and for steel wire $T_{-10} = 4300$ pounds, and for copper wire $T_{-10} = 3300$ pounds. So that:

For steel wire

$$\Delta T = 0{\cdot}166 \times 29{,}000{,}000 \times {\cdot}0000064 \times 100$$
$$= 3080 \text{ lbs.}$$
$$T_{90} = T_{-10} - \Delta T = 4300 - 3080 = 1220 \text{ lbs.}$$

and for copper wire

$$\Delta T = 0.166 \times 17{,}500{,}000 \times {\cdot}0000094 \times 100$$
$$= 2730 \text{ lbs.}$$
$$T_{90} = T_{-10} - \Delta T = 3300 - 2730 = 570 \text{ lbs.}$$

Since the tension variation is proportional to the temperature change, the Temperature *vs.* Stress curve is a straight line and may now be plotted (Fig. 2).

STRESSES IN FIVE-EIGHTH-INCH STRAND ON TANGENT, VARIOUS TEMPERATURES.

The curve assumed by the 5/8-inch messenger with the trolley wires hanging from it lies between a catenary and a parabola. The two curves lie very close together where the ratio of sag to span is small, and, as the parabola is much the simpler, it is used in these calculations.

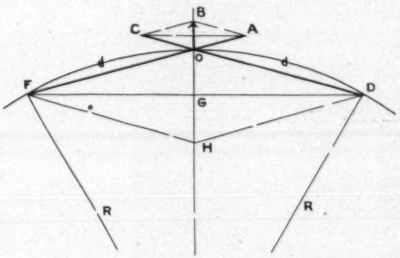
Assume parabola, Fig. 3, loaded w pounds per horizontal foot. Take moments about point of support. T = horizontal component of tension, s = sag in feet, d = span feet.

$$w \frac{d}{2} \frac{d}{4} = TS$$

$$s = \frac{wd^2}{8T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The total tension is, of course, greater than the horizontal component (the vertical component being the weight of the system), but the total weight is so small compared to the tension that the error is negligible.

FIG. 6.



The loadings (Table I) under maximum wind load with bare wires and with iced wires are:

Bare wires	2.185 pounds per foot vertical.
	2.740 pounds per foot horizontal.
	3.500 pounds per foot resultant.
With ice	4.159 pounds per foot vertical.
	2.165 pounds per foot horizontal.
	4.690 pounds per foot resultant.

Thus the maximum stress occurs when wires are coated with sleet, and is 4.69 pounds per foot. The normal span is 150 feet.

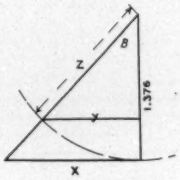
From equation (4)

$$s = \frac{4{\cdot}69 \times 150^2}{8 \times 8400} = 1{\cdot}57 \text{ ft. sag with wind and ice.}$$

The stress, 8400 pounds, is assumed lower than the allowed stress, since, with the stress equal throughout the system at 60°, the maximum stress is greater on curves than tangent.

The following expression for the length of a parabola is approximate only, but it is within the limits of accuracy of the field work:

FIG. 7.



$$l = d + \frac{8}{3} \cdot \frac{s^2}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

If the value:

$$s = \frac{wd^2}{8T}$$

be substituted in expression (5), we get

$$l = d + \frac{8}{3} \cdot \frac{\frac{w^2d^4}{64T^2}}{d}$$

$$= d + \frac{8}{3} \cdot \frac{w^2d^4}{64T^2} \cdot \frac{1}{d}$$

$$= d + \frac{w^2d^3}{24T^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Working from the above expressions, assuming that the maximum weight is 4.69 pounds per foot (resultant), the length of material in the span is, from equation (6),

$$l = 150 + \frac{4{\cdot}69^2 \times 150^2}{24 \times 8400^2}$$

$$= 150 + {\cdot}0438 \text{ feet.}$$

at −10° F., 8400 pounds tension.

This represents a definite quantity of material in the span, and, as the quantity of material does not change (the strand being clamped at the points of support), the effects of temperature and tension changes can be found.

Assume that the tension is reduced to, say, zero, then from equation (2),

$$l = l_0 + \frac{\Delta T l_0}{C.E}$$

$$= 150{\cdot}0438 - \frac{8400 \times 150{\cdot}0438}{0{\cdot}237 \times 26{,}000{,}000}$$

$$= 150{\cdot}0438 - 0{\cdot}2045$$

$$= 149{\cdot}8393 \text{ feet}$$

at $-10°$ F., zero tension.

This is less than the span, but that does not make any practical difference, as the reduction of the stress to zero is hypothetical.

Now, still considering the same quantity of material and assuming the stress is constant, 8400 pounds, let the temperature be 30°, 60°, and 90° F. respectively. The values of l are obtained from equation (1):

$$l = l_0 + l_0 (\Delta t. a)$$

So that, at 30°

$$l = 150{\cdot}0438 + 150{\cdot}0438 (40 \times {\cdot}0000064)$$
$$= 150{\cdot}0822 \text{ feet}$$

and at 60°

$$l = 150{\cdot}0438 + 150.0438 (70 \times .0000064)$$
$$= 150{\cdot}1110 \text{ feet}$$

while at 90°

$$l = 150{\cdot}0438 + 150{\cdot}0438 (100 \times {\cdot}0000064)$$
$$= 150.1398 \text{ feet.}$$

Since the elastic change in length due to temperature variations is independent of the temperature, there may now be plotted a series of "isothermal" lines, $-10°$, 30°, 60°, 90° tension *vs.* length for this quantity of strand. These lines will, of course, be parallel. On these "isothermal" lines may be plotted the lengths of parabola containing the same quantity of material, and loaded with any load w.

The normal load for the $\frac{5}{8}$-inch strand with the track wires

hanging from it is 2.185 pounds per foot (see Table I), and the length of a parabola under different tensions is given by equation (6):

$$l = d + \frac{w^2 d^3}{24\ T^2}$$

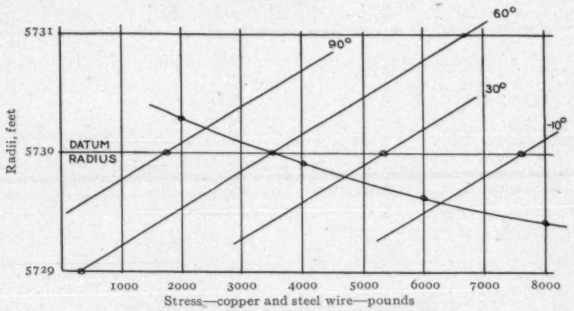
$$= 150 + \frac{2{\cdot}185^2 \times 150^3}{24\ T^2}$$

$$= 150 + \frac{674000}{T^2}$$

giving:

T	l
2000 pounds	150.168 feet
3000 pounds	150.075 feet
4000 pounds	150.042 feet
5000 pounds	150.027 feet
6000 pounds	150.019 feet
7000 pounds	150.014 feet
8000 pounds	150.011 feet

FIG. 8.



To show stress in copper trolley and steel contact wires for various temperatures, 1° curve.

Temperature	Combined stress
−10°	6300 pounds
30°	4700 pounds
50°	3500 pounds
90°	2400 pounds

If this curve be superimposed on the other lines, the points of intersection indicate the tension that exists in the strand at those various temperatures with this particular loading (which is the normal load).

Another set of parabola lengths, showing the strand with only its own weight as load, may also be plotted. This latter load is

0.810 pound per foot (Table I). Using equation (6) again, we get

$$l = d + \frac{w^2 d^3}{24 T^2}$$

$$= 150 + \frac{0.810^2 \times 150^3}{24 T^2}$$

$$= 150 + \frac{37610}{T^2}$$

giving:

T	l
1000 pounds	150.0376 feet
2000 pounds	150.0094 feet
3000 pounds	150.0042 feet
4000 pounds	150.0021 feet
5000 pounds	150.0015 feet
6000 pounds	150.0011 feet

The intersections of this curve with the isothermal lines give the stress at these various temperatures of the strand with only its own weight, and this data may be used in pulling up the messenger (see Fig. 4).

Knowing the appropriate stresses at various temperatures, we can find sags for any span. Since a span length of 150 feet was taken as a basis, the results are not accurate for spans of other lengths, as the temperature effect is not the same, being greater for shorter spans, and *vice versa*. Nevertheless, as the error is not very great (when the variation in length of span is small), and since to take care of it would complicate the calculation considerably, this feature is ignored.

The corresponding hangers for all lengths of span are the same; that is, for instance, the six shortest hangers of a 200-foot span are the same as the six hangers of a 60-foot span.

The hangers are spaced approximately 10 feet apart. Thus, for spans containing an *even* number of hangers the lengths are different from those containing an *odd* number, and two sets of lengths are provided, one set (for "odd" spans) with one shortest hanger, and one set (for "even" spans) with two "shortest" hangers.

From the curve, Fig. 4, the stresses are:

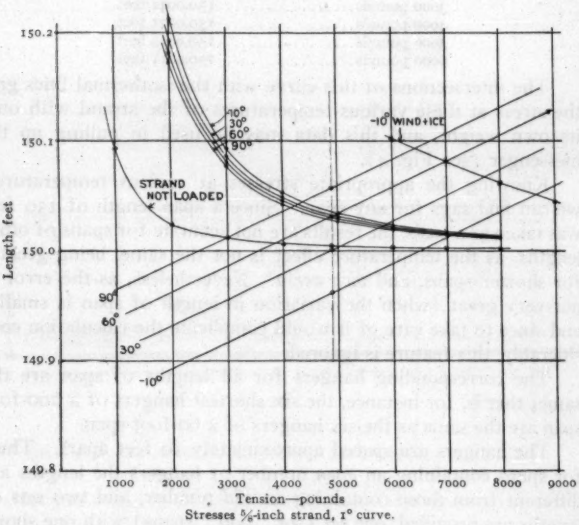
		−10° wind and ice	−10°	30°	60°	90°
Stress in pounds in ⅜-inch strand	Not loaded	—	6600	5100	4000	3000
	Normal load	8400	7100	5800	4900	4200

To find the sag for various spans at the different temperatures, equation (4) applies:

$$S = \frac{w\,d^2}{8\,T}$$

the load per foot and the tensions at various temperatures being known. The values of sag for various spans, both for pulling up the strand and for finding the final position of the strand under load, are plotted in Fig. 19.

FIG. 9.



Stresses ⅝-inch strand, 1° curve.

CURVE CONSTRUCTION.

As is indicated above, the trolley and contact wires lie in a smooth curve following the track curves. The hangers are, therefore, inclined at an angle which is the resultant of their weight and the horizontal pull of the trolley and contact wires.

The stresses on curves are found just as on tangents, there being only the added load due to the curve. All the loads are resolved into vertical and horizontal components, and the sags

are also resolved into vertical and horizontal components, the total deflection or sag of the messenger being the resultant.

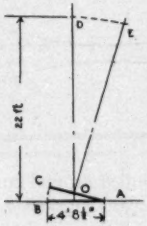
The tension of the trolley and contact wires causes the curve load, and this is found as follows: Assume a track curve making a complete semicircle (Fig. 5), the contact and trolley wires being pulled to coincide with this curve. There is a horizontal force acting on these wires of, say, w pounds per foot to keep them in position. Referring to Fig. 5, if

T = Tension in wires, pounds.
F = Horizontal force normal to wires, pounds.
d = Span in feet.
R = Radius of curve in feet.

On any element $R.d\rho$ the force acting on the wire is $w.R.d\rho$, and the component normal to the diameter would be

$$w.\ \sin\phi.\ d\rho = dF$$

FIG. 10.



Integrating between $\rho = 0$ and $\rho = \pi$, we get

$$F = w.R \int_0^{\pi} w.\ \sin\phi.\ d\rho$$

$$= w.R \left(-\cos\phi\right)_0^{\pi}$$

$F_0 = 2\,w.R$ for entire semicircle. This is resisted by the wire at each end of the semicircle, or by the force $2T$. Thus

$$2\,T = 2\,w.R$$

$$w = \frac{T}{R} \qquad \ldots\ldots\ldots\

For a small arc in the circle subtending angle m symmetrical about centre line,

$$F = 2\,w.R.\cos m$$

if $$d = 2\,R.\cos m$$

(which it does nearly if m is small).

Substituting

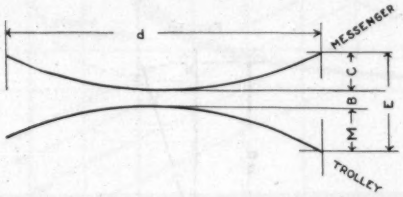
$$T = w.R$$

we get

$$F = w.d = \frac{T.d}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

It is interesting to note that it makes practically no difference in what shape the wires are pulled around a curve, whether in a smooth arc or in chords, the force required to keep them in position is the same, if the curve is not too sharp.

FIG. 11.



Suppose wires are pulled around curves in a series of chords FOD in Fig. 6. Two spans marked d are shown in this figure. The force required to keep the wire in position is OB, the tension in the wire being $OA = OC = T$. Parallelograms $FODH$ and $CBAO$ are similar, so

$$\frac{OB}{2OG} = \frac{OA}{OD}$$

but $OB = F$ and $OA = T$ (where F is the force required to pull the wires off in the proper position and T is the tension in the wires).

$$OG = 6D \text{ (nearly)} = d \text{ (span)}$$

therefore

$$OG = R - \sqrt{R^2 - d^2} = OD$$

Substituting

$$\frac{F}{2(R-\sqrt{R^2-d^2})}=\frac{T}{D}$$

or

$$F=\frac{2T\,(R-\sqrt{R^2-d^2})}{d}$$

Expand $\sqrt{R^2-d^2}$ by binomial theorem

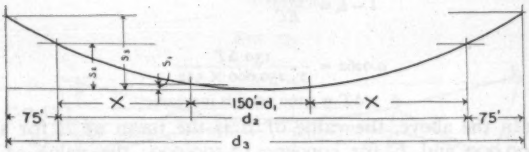
$$[(a+b)^n=a^n+na^{n-1}b+\ldots\ldots\ldots]$$

$$\sqrt{R^2-d^2}=R+\frac{1}{2}R^{-1}\left(-d^2\right)+\ldots\ldots\ldots$$

(neglect rest of terms)

$$=R-\frac{d^2}{2R}$$

FIG. 12.



Substitute in above

$$F=\frac{2T\left(R-R-\frac{d^2}{2R}\right)}{d}$$

$$=\frac{2Td}{R}\text{ for both spans}$$

or

$$F=\frac{Td}{R}\qquad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

which is similar to equation (8).

This identity is useful in finding forces acting on catenary bridges.

The tension in the copper and steel wires on curves is not the same as on tangents at all temperatures, because the inclination of the hangers varies with temperature variations, and as the inclination increases the radius of the circumference on which the wires lie is reduced, and the tension therefore varies less than on tangents.

There is very little taking up or paying out of wire from tangents to curves, and *vice versa*, because the hangers are rigidly

fastened to the 5/8-inch messenger and the copper wire on tangents and to the 5/8-inch messenger and steel wire on curves, and the 5/8-inch messenger is held tightly at the insulators.

Assume a stress of 2100 pounds in the steel and 1400 pounds in the copper wires at 60° F. The radius of a 1° curve is 5730 feet, and we can consider the wires running along a circumference of that radius. Sum of stresses = 3500 pounds. Now suppose the wires move out so they lie on a curve of 5731 feet radius. The length of a 150-foot arc will increase

$$\frac{5730}{1} = \frac{150}{x} = 0.0262 \text{ feet}$$

and will now be 150.0262 feet. Transposing equation (2), we have

$$l - l_0 = \frac{\Delta T . l_0}{EC}$$

or

$$0.0262 = \frac{150\ \Delta T}{23{,}250{,}000 \times 332}$$

$$\Delta T = 3190 \text{ pounds increase.}$$

(In the above, the value of E is the mean of E for steel = 29,000,000 and E for copper = 17,500,000; the value of C is 2 x 0.166.)

If the radius is reduced to 5729 feet, the reduction in stress would be practically the same quantity, 3190 pounds; *i.e.*,

Radius 5729 feet.	Tension 3500−3190 =	310 pounds
Radius 5730 feet.	Tension	=3500 pounds
Radius 5731 feet.	Tension 3500+3190 =	6690 pounds

assuming temperature constant, 60° F.

These values may be plotted, stress *vs.* radius, as an "isothermal" line. The line will be practically straight (Fig. 8).

If the temperature becomes −10°, 30°, and 90° respectively, it may be assumed that the wires lie on a curve of 5730 feet radius at each of these temperatures, the stress of the two wires being, in each case:

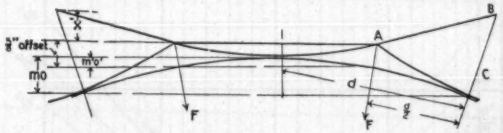
Temperature	−10°	30°	90°
Stress, pounds...	3300	2200	570
	4300	3100	1220
	7600	5300	1790

These values may be plotted as "isothermal" lines parallel to the 60° line (Fig. 8).

The length of wire corresponding to various inclinations of hanger rod is found thus: The vertical component is 0.641 (copper) +0.558 (steel) +0.177 (hanger) [see Table I] = 1.376 pounds per foot, and is constant. The horizontal component is the value of w in the equation $w = \frac{T}{R}$ (equation 7). Call this horizontal component x, and let β be the inclination of the hanger, z the length of the longest hanger (= 1.83 feet ±), and y the horizontal displacement of the wires. Then, referring to Fig. 7,

$$\tan \beta = \frac{x}{1.376}$$
$$y = z \sin \beta$$
$$= 1.83 \sin \beta$$

FIG. 13.



If various values of the stress are assumed, corresponding values of x calculated from equation (7) and of tan β and y from the above, the distances of wires from datum point at 60° F. in Table II are obtained.

TABLE II.

Assumed stress in pounds	Value of x in pounds from equation (7), R=5730	tan β	sin β	y	Distance of wires from datum (60° F.)
2000	0.349	0.254	0.246	0.450	0.294 outside
3500	0.611	0.444	0.406	0.744	datum
4000	0.699	0.508	0.453	0.830	0.086 inside
6000	1.047	0.761	0.606	1.111	0.367 inside
8000	1.396	1.015	0.712	1.302	0.558 inside

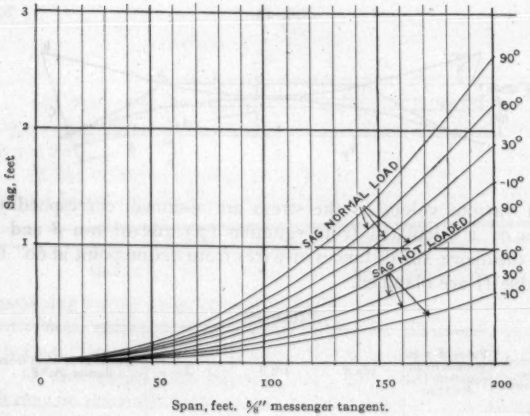
If the stress of 3500 pounds is considered the basis of calculations, the location of the wires at this tension is the datum point, and the distance away from that point (5730 feet radius)

may be plotted for the various tensions, over the "isothermal" lines, the intersections being the tension of the copper and steel wires combined for the corresponding temperature (Fig. 8). These stresses of the copper and steel grooved wires give the horizontal load components on the 5/8-inch messenger:

$$w = \frac{T}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

	−10°	30°	60°	90°
T	6300	4700	3500	2400
R	5730	5730	5730	5730
w	1.100	0.821	0.611	0.418

FIG. 14.



The vertical load, as on tangent, is 2.185 pounds per foot, so that the resultant loads are:

−10°.....2.442 pounds per foot
30°.....2.331 pounds per foot
60°.....2.270 pounds per foot
90°.....2.220 pounds per foot

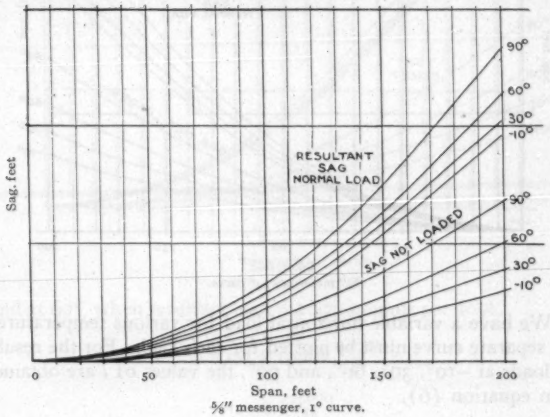
Assume stress of 4900 pounds in the 5/8-inch messenger at 60° F. (the stress on the whole system, tangent and curves, is 4900 pounds at 60° F.), then the sag s is given by equation (4):

$$s = \frac{wd^2}{8T}$$
$$= \frac{2.27 \times 150^2}{8 \times 4900}$$
$$= 1.30 \text{ feet.}$$

Now to find the length of material in this span, use equation (5),

$$l = d + \frac{8s^2}{3d}$$
$$= 150 + \frac{8}{3} \cdot \frac{1.30^2}{150}$$
$$= 150.0301 \text{ feet.}$$

FIG. 15.



Assume tension raised to, say, 8900 pounds, temperature remaining 60° F., from equation (2)

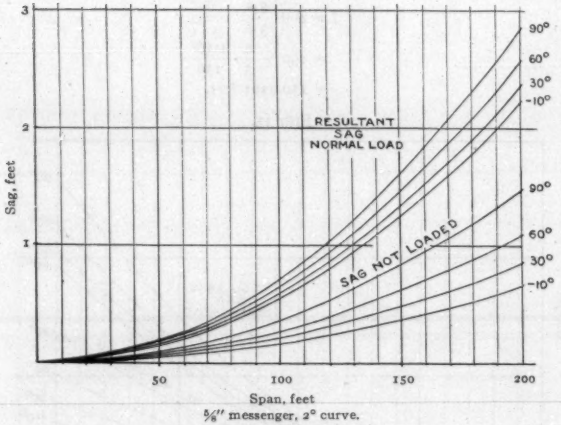
$$l = l_0 + \frac{\Delta T . l_0}{CE}$$
$$= 150.0301 + \frac{4000 \times 150.0301}{0.237 \times 26{,}000{,}000}$$
$$= 150.1276 \text{ feet.}$$

Assume temperature changes to −10°, 30°, 90°, respectively, the tension remaining at 4900 pounds, from equation (1)

$$l = l_0 + l_0 . \Delta t . \alpha$$
$$= 150.0301 + 150.0301\ (.0000064\ \Delta t)$$
$$= 150.0301 + 0.00902\ \Delta t$$

so that, at −10° $l = 150.0301 - 0.0673 = 149.9628$ feet
at 30° $l = 150.0301 - 0.0282 = 150.0019$ feet
at 90° $l = 150.0301 + 0.0282 = 150.0583$ feet

FIG. 16.



⅝″ messenger, 2° curve.

We have a variable horizontal load for various temperatures, so a separate curve must be plotted for each load. For the resultant loads at −10°, 30°, 60°, and 90°, the values of l are obtained from equation (6),

$$l = d + \frac{w^2 d^3}{24 T^2}$$
$$= 150 + 140600 \frac{w^2}{T^2}$$

so that at −10°, when resultant load = 2.442 pounds per foot,

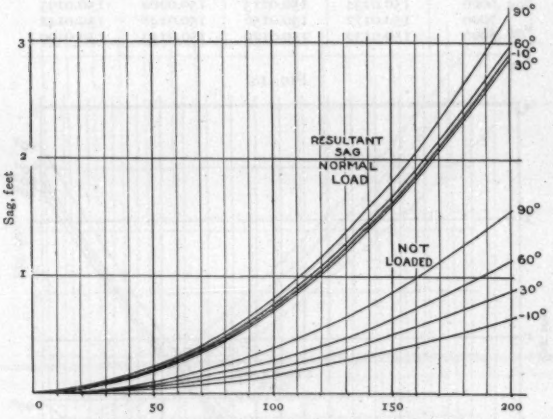
$$l = 150 + 140600 \frac{2.442^2}{T^2}$$
$$= 150 + \frac{842000}{T^2}$$

and at 30°, when resultant load = 2.331 pounds per foot,

$$l = 150 + 140600\,\frac{2.331^2}{T^2}$$

$$= 150 + \frac{767000}{T^2}$$

FIG. 17.



⅝" messenger, 3° curve.

and at 60°, when resultant load = 2.270 pounds per foot,

$$l = 150 + 140600\,\frac{2.270^2}{T^2}$$

$$= 150 + \frac{725000}{T^2}$$

and at 90°, when resultant load = 2.220 pounds per foot,

$$l = 150 + 140600\,\frac{2.220^2}{T^2}$$

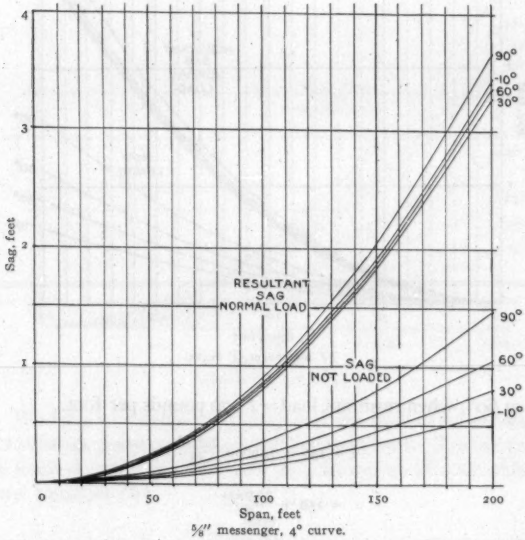
$$= 150 + \frac{695000}{T^2}$$

Substituting the various values of T, we get the values of l in Table III.

TABLE III.

T	l_{-10}	l_{30}	l_{60}	l_{90}
2000	150.211	150.192	150.181	150.174
3000	150.0935	150.0853	150.0805	150.0772
4000	150.0526	150.0479	150.0454	150.0434
5000	150.0336	150.0306	150.0290	150.0278
6000	150.0234	150.0213	150.0202	150.0193
7000	150.0172	150.0156	150.0148	150.0142
8000	150.0132	150.0120	150.0113	150.0109

FIG. 18.



⅝″ messenger, 4° curve.

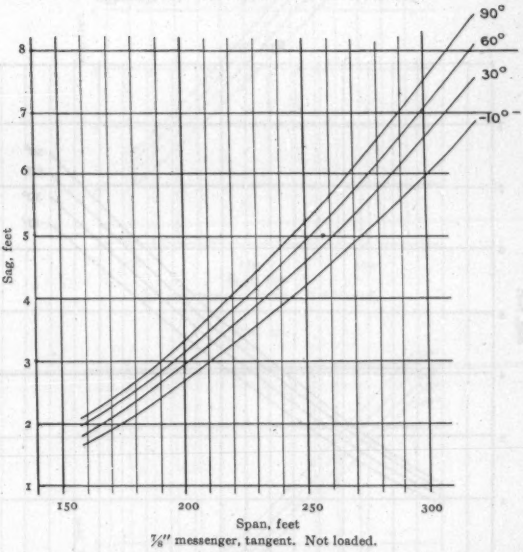
To find the stresses at various temperatures with no load except the weight of the strand itself, which is 0.810 pound per foot:

$$l = 150 + \frac{0.810 \times 150^3}{24T^2}$$

$$= 150 + \frac{92500}{T^2}$$

T	l
1000	150.0925
2000	150.0231
3000	150.0103
4000	150.0058
5000	150.0037
6000	150.0025
7000	150.0019
8000	150.0014

FIG. 19.



⅞″ messenger, tangent. Not loaded.

The maximum load on a 1° curve occurs with ice and wind. The wind acting on the trolley and contact wires, however, tends to throw slack into them and reduce their tension, so that item may be omitted.

	Vertical	Horizontal
Load	4.159 pounds per foot.	
Wind load (as above)		0.845 pounds per foot
Curve load, −10° F		2.442 pounds per foot
	4.159	3.287

Resultant = 5.30 pounds per foot.

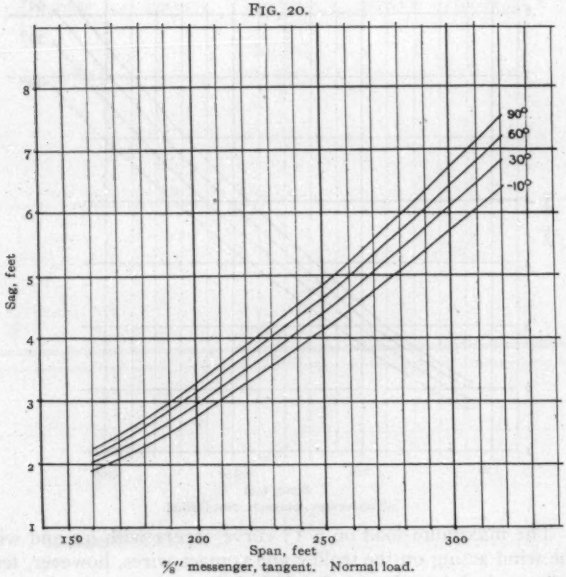
Plot another curve for this load, as before, to find maximum load.

$$l = 150 + \frac{5.30^2 \times 150^3}{24T^2}$$

$$= 150 + \frac{3975000}{T^2}$$

T	l
6000	150.101
7000	150.0812
8000	150.0622
9000	150.0490

FIG. 20.

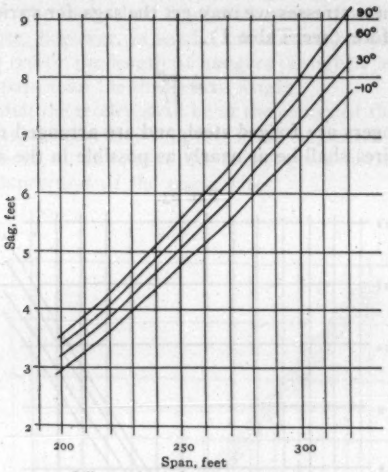


⅞" messenger, tangent. Normal load.

From the curves plotted (Fig. 9) the stresses for the strand, under normal curve loads, are:

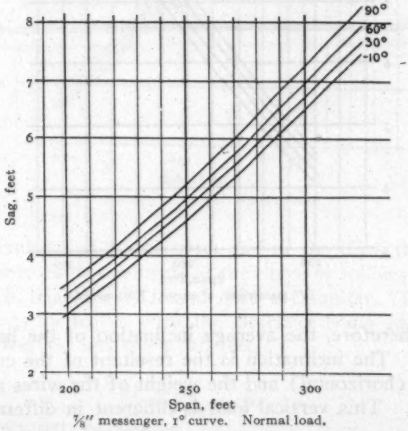
	−10° wind and ice	−10°	30°	60°	90°
Not loaded...	—	6600	5000	3900	3000
Normal load..	8700	7200	5800	4900	4200

FIG. 21.



⅞″ messenger, 1° curve. Not loaded.

FIG. 22.



⅞″ messenger, 1° curve. Normal load.

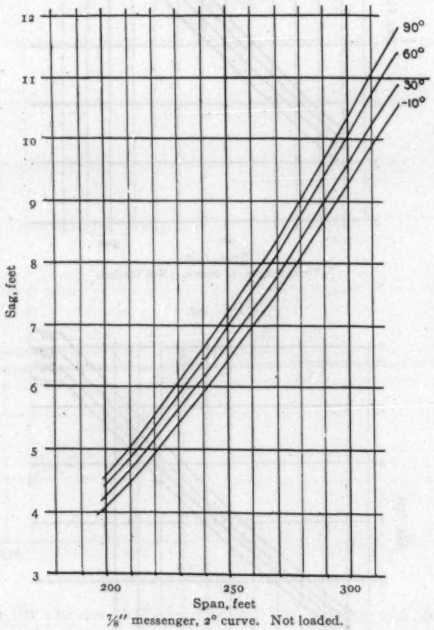
Maximum stress with wind and ice, 8700 pounds.

From these stresses we may get the sags for various temperatures as before (see Table I).

$$s = \frac{wd^2}{8T}$$

The hangers are forged steel, and are arranged so the copper and steel wires shall be as nearly as possible in the same vertical

FIG. 23.



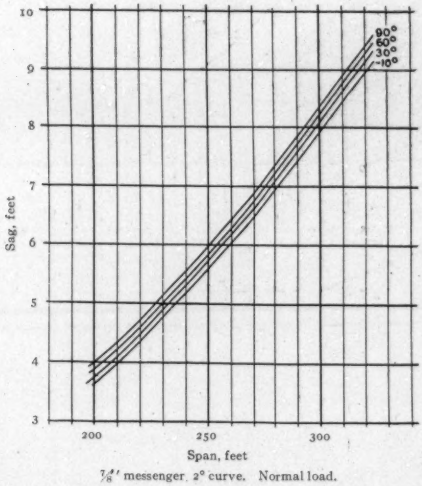
⅞" messenger, 2° curve. Not loaded.

plane. Therefore, the average inclination of the hangers must be found. The inclination is the resultant of the curve pull of the wires (horizontal) and the weight of the wires and hangers (vertical). This vertical load is different in different portions

of the span—the hangers at the ends being longer than those near the centre—so the inclination is slightly greater near the centre. This difference, however, is small, and a mean is easily found. For the same reason the length of hangers is slightly less near the ends of the spans than the theoretical length.

In order that the trolley shall be at the centre of the collecting shoe on curves, the catenary supports must be located on the outside of the curve, so as to give the messenger a horizontal component to balance that of the track wires.

FIG. 24.



⅞″ messenger. 2° curve. Normal load.

The superelevation of the outer rail of the track throws the collector shoe towards the inside of the curve as follows:

In Fig. 10, triangles OED and ABC are similar. Therefore, if D represents the trolley wire, the clearance being 22 feet, and the gauge 4 feet 8½ inches = 4.716 feet,

$$\frac{DE}{CB} = \frac{22}{4.716} = 4.65$$

that is, each inch of superelevation throws the collector shoe over about 4.65 inches, and this must be subtracted from the distance the insulator must be offset toward the outside of the curve.

The other elements of the offset calculations are (Fig. 11):

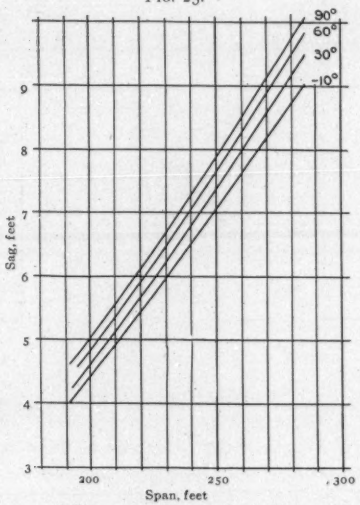
M = Mid-ordinate of track curve for span.
B = Horizontal projection of shortest hanger.
C = Horizontal projection of sag of messenger.
E = Total offset distance $- M+B+C$.

The distance B is a constant for 1° curve hangers 0.2 foot.

The horizontal component of the sag is found from the horizontal load $w = 0.611$ pound per foot, and the tension 4900 pounds.

$$s = \frac{wd^2}{8T}$$

FIG. 25.



⅞″ messenger, 3° curve. Not loaded.

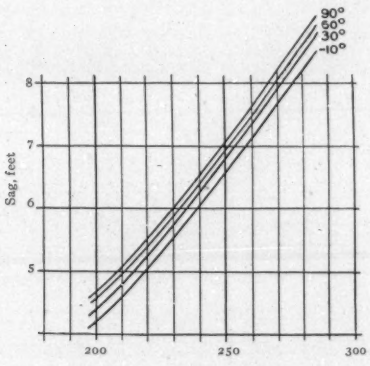
The computations for 2°, 3°, and 4° curves are made in the same way as 1° curve, except that the assumed span for 3° curve is 130 feet and 4° curve is 100 feet, instead of 150 feet.

CALCULATIONS FOR SEVEN-EIGHTH-INCH STRAND.

The calculations for the 7/8-inch strand are similar to those for the 5/8-inch strand, but the 7/8-inch catenary is broken at each *I*-beam support (Fig. 1). For purposes of computing the sags, etc., the weight of the *I*-beams, insulators, track catenaries, etc., is considered as replaced by a length of 7/8-inch strands of equal weight (length X in Fig. 12). Thus the 7/8-inch strand would lie in a smooth curve whose length would be $300 + 2X$ feet and the sag of which would be $s_3 - s_2 + s_1$ (see Fig. 12).

The computation of stress for various temperatures is made like that of 5/8-inch strand.

FIG. 26.



7/8" messenger, 3° curve. Normal load.

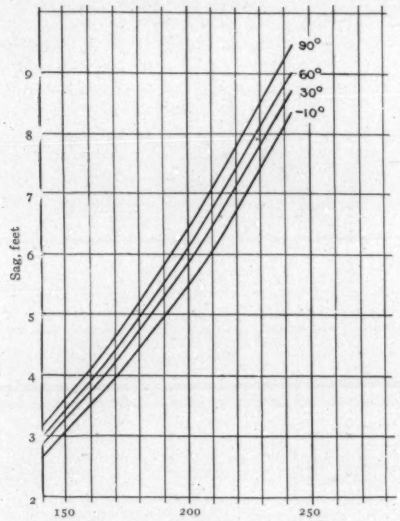
The ratio of the weight of the entire catenary system to the stress in the 7/8-inch messenger is so large that the difference between the horizontal component of the stress and the total stress is not negligible. The total stress is the resultant of the weight and horizontal tension. The 7/8-inch strand is clamped to the catenary bridges by malleable iron saddles, so that once strung the quantity of strand in a given span cannot change.

In the case of the short spans, the *I*-beam is not clamped close to the 7/8-inch strand, because the resulting small sag would raise the trolley too high. Hangers of 2½ x 2½-inch galvanized angle

iron were inserted between the *I*-beam and 7/8-inch strand to bring the *I*-beam to the correct height, so standard hangers could be used.

The horizontal component of the sag on curves is found as follows: The entire curve load is concentrated at the *I*-beam; let this be *F*. This is caused by the trolley wires and the 5/8-inch

FIG. 27.



7/8" messenger, 4° curve. Not loaded.

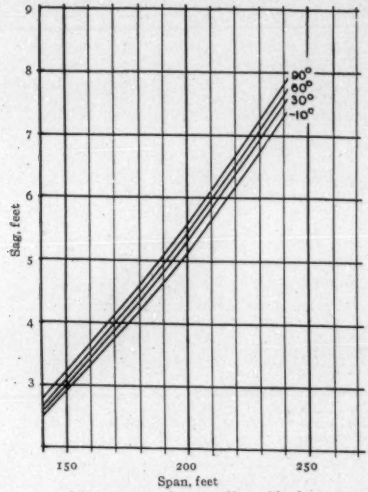
strand (Fig. 2 stress in wires = 3500 pounds; Fig. 4 stress in 5/8-inch strand = 4900 pounds), these figures holding for all curves at 60° F.

The stresses in the wires and messenger may be added together [equation (8)].

$$F = \frac{Td}{R}$$

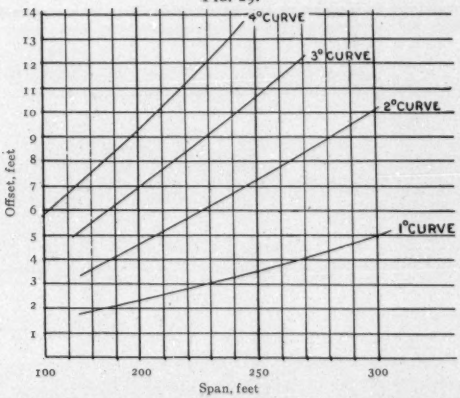
$$= \frac{8400d}{R}$$

FIG. 28.



7/8" messenger, 4° curve. Normal load.

FIG. 29.

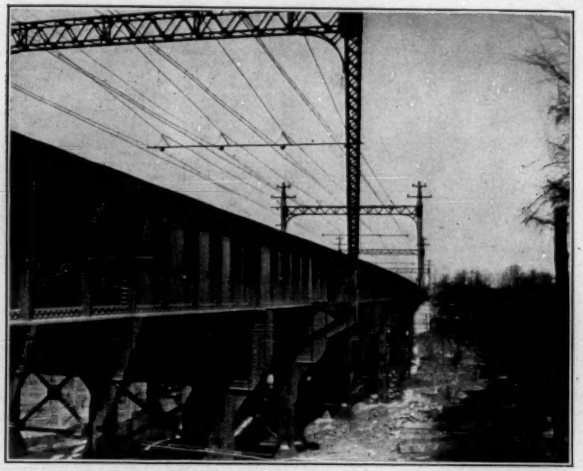


Offsets of saddles for ¼-inch strand from centre line of track toward outside of curve.
(Correction for superelevation of outer rail to be subtracted.)

The horizontal component of the tension in the 7/8-inch strand is 7180 pounds at 60°.

From Fig. 13,

$$\frac{F}{7180} = \frac{x'}{\frac{d}{2}} \quad \text{(nearly)}$$



30 curve. Showing also spacer hangers between *I*-beam and 7/8" strand where spans are less than 300 feet.

Substituting

$$F = \frac{8400d}{R}$$

$$\frac{d^2}{2} \times \frac{8400}{7180} = x'$$

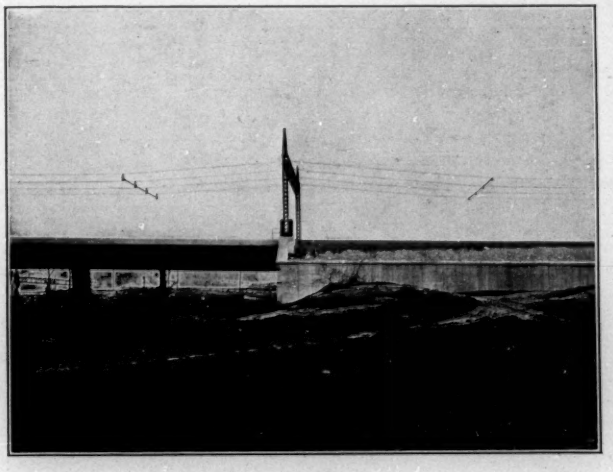
$$x' = \frac{0.585d^2}{R}$$

The offset (exclusive of superelevation) is $mo - m'o' +$ 5/8 offset $+ x'$.

TABLE IV.

Stresses, in Pounds, in ⅝-inch Messenger, Various Temperatures.

Temperature	−10°	30°	60°	90°
Tangent:				
Not loaded.....	6600	5100	4000	3000
Normal load...	7100	5800	4900	4200
1° curve:				
Not loaded.....	6600	5000	3900	3000
Normal load...	7200	5800	4900	4200
2° curve:				
Not loaded.....	6300	4800	3700	2700
Normal load...	7300	5800	4900	4200
3° curve:				
Not loaded.....	6200	4700	3600	2600
Normal load...	7600	6000	4900	4000
4° curve:				
Not loaded.....	6500	5000	3900	2800
Normal load...	7700	6100	4900	3900



Tangent construction.

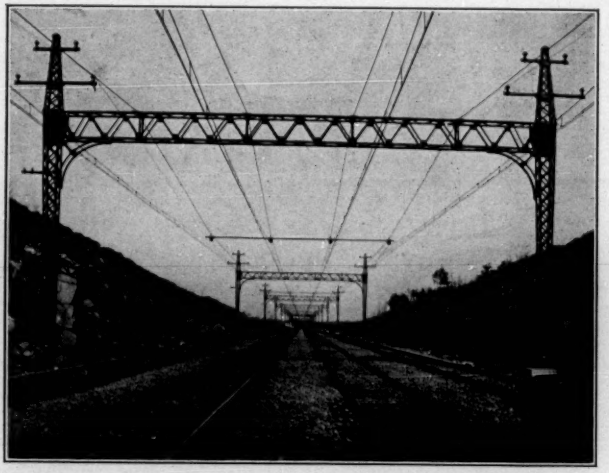
Average inclination of hanger from vertical:

Tangent	0
1° curve	28°
2° curve	48°
3° curve	58°
4° curve	63°

TABLE V.

Stresses, in Pounds, in ⅞-inch Strand, Various Temperatures.

Temperature	−10°	30°	60°	90°
Tangent:				
No load.....	3200	2900	2700	2550
Normal load...	8500	8000	7550	7200
1° curve:				
No load.....	2850	2650	2500	2400
Normal load...	9200	8200	7550	7000
2° curve:				
No load.....	3000	2000	1900	1850
Normal load...	10100	8500	7550	6850
3° curve:				
No load.....	2000	1800	1750	1700
Normal load...	11500	9150	7550	6800
4° curve:				
No load.....	1550	1450	1400	1300
Normal load...	11600	9150	7550	6400



Tangent construction.

MAXIMUM LOAD DUE TO CATENARY CONSTRUCTION ON BRIDGES.

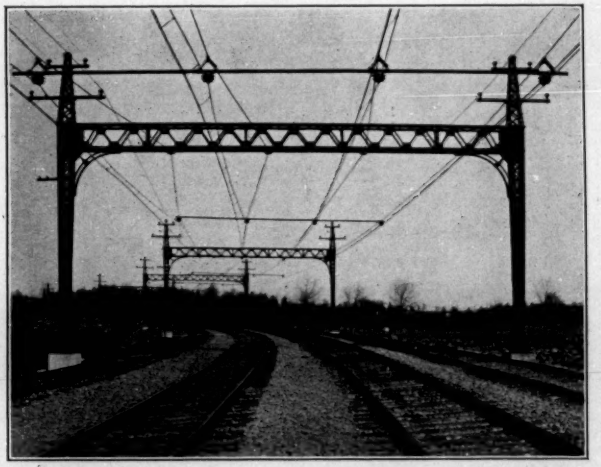
Three general types of bridges were used, as follows:

(*a*) "Tangent," for tangent track only.

(*b*) "1° curve," for curves up to 1° inclusive.

(*c*) "4° curve," for all curves over 1°—with pull-off for curves over 4°.

The total vertical load is the sum of the loads in column 6, Table I, and is 6.711 pounds per foot, while the total wind load is the sum of the loads in column 8, and is 3000 pounds per foot.



4° curve.

The weight of the *I*-beam, ice-coated, is 105 pounds per track, and of the insulators and clamps is taken as 40 pounds per track. The *I*-beam and insulator wind load is taken as 10 pounds per track. So that:

For 300-foot span

Vertical load $= 6.711 \times 300 + 105 \times 2 + 40 \times 2 = 2300$ pounds per track.
Wind load (horizontal) $= 3.000 \times 300 + 10 \times 2 = 920$ pounds per track.

For 260-foot span

Vertical load = $6.711 \times 260 + 102 \times 2 + 40 \times 2 = 2030$ pounds per track
Wind load (horizontal) = $3.000 \times 260 + 10 \times 2 = 800$ pounds per track

and for 200-foot span

Vertical load = $6.711 \times 200 + 105 \times 2 + 40 \times 2 = 1630$ pounds per track.
Wind load (horizontal) = $3.000 \times 200 + 10 \times 2 = 620$ pounds per track.

The curve pulls are obtained from equation (8):

$$F = \frac{Td}{R}$$

For 5/8-inch strand, $T = 9000$ pounds, and for 7/8-inch strand, $T = 18{,}000$ pounds. For the track wires, $T = 7600$ pounds. Therefore total $T = 34{,}600$ pounds.

The radius of 1° curve is 5730 feet; of 2° curve, 2865 feet; of 3° curve, 1910 feet, and of 4° curve, 1432 feet.

Hence:

For 1° curve

$$F = \frac{34600 \times 300}{5730} = 1810 \text{ pounds.}$$

For 2° curve

$$F = \frac{34600 \times 300}{2865} = 3620 \text{ pounds.}$$

For 3° curve

$$F = \frac{34600 \times 260}{1910} = 4710 \text{ pounds.}$$

For 4° curve

$$F = \frac{34600 \times 200}{1432} = 4840 \text{ pounds.}$$

Adding these curve pulls to the horizontal wind pulls above, we get the total horizontal loads, as follows:

For 1° curve.....2730 pounds.
For 2° curve.....4540 pounds.
For 3° curve.....5510 pounds.
For 4° curve.....5460 pounds.

The load of the feeders and the wind load of the structure itself are added to the above loads in designing the steel bents.

SOME RECENT ADVANCES IN PHOTOGRAPHY.*

BY

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Member of the Institute.

ALTHOUGH for some years past the labors of many expert photographers have been largely directed to the so-called "artistic" side of photography, the purely technical and scientific sides have not been wholly neglected, and an inspection of the current journals and recent books will show many interesting results. The basic procedures for development, fixing, and toning have suffered but little change during many years. The competitive spirit has led to the introduction of many new developers, but most of these are minor modifications of the original forms, especially as regards the benzene derivatives, and in some cases the change is in name only. A conspicuous instance of the latter is in the use by the Lumière Company of the terms "quinomet" and "metoquinone" in their formula for color-plate work, the information at hand indicating that the names refer to the same substances and that this is merely an intimate mixture of metol and hydroquinone.

Probably the most important, at least the most generally exploited, advance in procedure in this field is color-photography. It is curious to note that in the first edition of his work on methods of photography M. Carey Lea stated that, in his opinion, color-photography was impossible, and he gave his reasons for this view. Not long after he modified his view, in consequence of the results of research, so far as to admit the possibility of such photography. He would surely be interested in some of the plates made to-day by the several processes that are extensively employed, and yet he could truly say that the results obtained by the Lumière, Dufay, and Paget plates are not really "color-photography," but colored photographs in which the hand of the artist has been substituted by ingenious automatic processes.

One of the latest applicants for favor in this line is the Paget

*Abstract of remarks made at the meeting of the Section of Photography and Microscopy, held October 15, 1914.

plate. This utilizes a color screen involving the same principle as the older methods,—that is, an even distribution of the three colors,—but in the Paget plate this screen is detachable and hence may be used for many plates. Moreover, the reversion of the image as followed by the older methods is substituted by using the plate as a negative, and attaching a viewing screen to a positive made in the usual manner. Paget screens are much more transparent than Lumière screens, and hence more satisfactory for lantern demonstration; on the other hand, they are much coarser, and a considerable magnification, as when a slide is projected on large extent, shows the individual colors and destroys the illusion. The total cost of a complete Paget lantern slide is slightly higher than that of a Lumière, but if the operator has a considerable proportion of failures, Paget methods are more economical. In sizes of the individual color areas the Paget screens agree closely with those of the Dufay and Thames plate (the latter is now out of the market).

It is well known to working photographers that the Lumière process employs the principle of reversion of image, as the transparency obtained by fixing after first development shows all colors complementary. Working with the color-plates suggested to me to try some of the reversal processes with ordinary plates,—that is, to obtain positives by one exposure. In the early days of negative making, the so-called wet plates, the possibility of direct positives was investigated and several methods were devised. These can be applied to the ordinary dry plates with much success, and, although such procedures are of no great practical value or wide application, they afford an interesting field for experiment by amateurs.

My experience has been principally with the following method:

Good exposure and good development are given, the developer is washed off and the plate stood, coated side outward, in a developing dish of black material (or the plate is backed by black paper), and several inches of magnesium ribbon are burned a few inches from it. The silver deposit acts as a negative, and the unchanged silver compounds are light-struck. The plate is then immersed in a solution of potassium dichromate and sulphuric acid, such as is used in reversing Lumière color-plates, until the image has practically disappeared. The plate is washed for a minute or so, immersed for a few minutes in a 5 per cent. solution

of sodium sulphite, and then returned to the developer. The second development gives, of course, a positive, which is then fixed and washed as usual. Theoretically, no fixing is needed, but, in practice, it is best to put the plate through the regular "hypo" solution. The second development will usually be rather slow. It must also be borne in mind that plates well wetted by developer are much less sensitive to light than plates in the dry condition, hence, if the first development has given a dense picture, a good length of magnesium ribbon should be burned within a few inches of the plate. Care must be taken not to look at the flame, and to hold the ribbon with a pair of tongs. All operations are conducted in the dark room. The process will be found useful for making slides in an emergency.

Among the striking discoveries in relation to light, or, it will be more precise to say, radiant energy, is the existence of rays and material emanations which are invisible to the unassisted human eye, but affect ordinary photographic films and many other substances, and, in some cases, pass freely through objects opaque to ordinary light.

Upon such phenomena as the X-rays, emanations from radioactive substances, ultra-violet and infra-red light I need not dwell here, as ample discussion of these is to be found in recent literature. I want, however, to call attention to a less exploited field, although, even in this, the basic procedures are not very recent. I refer to what has been called "picture-making in the dark," inasmuch as the etymology of the word "photography" prevents us from applying it to any processes but those in which light takes part. I need not stop to give any elaborate history of the investigations. An early contribution was that by W. J. Russell before the Royal Society (*Science*, 1900, 11, 487), who tried many substances and obtained curious results from some of them. M. I. Wilbert (JOURNAL FRANKLIN INSTITUTE, 1900, cl, 388) repeated some of Russell's experiments with success. In reviewing these papers, however, it seemed to me that in many cases the impression on the photographic plate might be due to pressure, or mere physical contact, rather than an emanation tangible or intangible. I wish to say, frankly, that I have failed to obtain many of the results reported by Russell and Wilbert, even though following their methods as closely as the descriptions available enable. In the later series of experiments I adopted the plan of interposing

thin paper, usually the ordinary lantern mat, between the object and the sensitive plate, thus preventing actual contact. This method materially retards the action.

It has seemed to me that the procedures that I intend to summarize briefly may be called skotography (from Greek *skotos*, darkness). One of the most active skotographic surfaces is obtained by scratching or polishing common zinc battery plates. Thin zinc sheets do not seem to be so active, nor does sand-papering the zinc plates yield very good results. If one scratches on a tarnished and corroded zinc plate a design, by means of a sharp steel tool, and then lays a dry plate (I used ordinary lantern plates) upon this, with a thin paper between with some perfora-

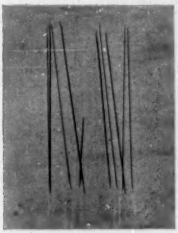
Negative produced by aluminum.

Negative produced by Eastman "Flash-sheet."

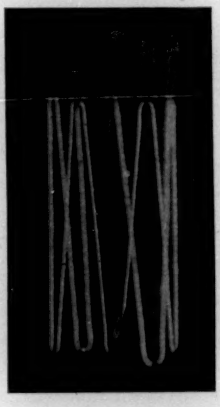
tion or a cut-out design, and allows this combination to remain in the dark for a couple of days, a distinct impression will be made on the sensitive plate that can be brought out by ordinary development. Often the metal is active enough to produce a marked effect in a few hours. Russell expressed the opinion that emanations of minute amounts of hydrogen dioxide produce the effects, and that the dioxide is in some way formed by the fresh surface of metal, but I have not yet obtained any information to enable me to form an opinion as to the cause. Magnesium and zinc seem to be specially active; thin sheet iron did not produce any effect. Aluminum has moderate activity. I obtained a strong effect with the so-called "Flash-sheets" manufactured by the Eastman Kodak Company. Bibulous paper impregnated with old oil of turpentine gave no appreciable effect, but impregnated with

commercial solution of hydrogen dioxide and allowed to get nearly dry before testing gave a feeble picture.

Some experiments have been made on the photographic and other properties of commercial luminous paint. This seems to be composed largely of calcium sulphide in a fixed oil. I have used it spread on glass plates and have found the most convenient way to get an even coating is to dilute the material with gasoline and pour the mixture, as was the custom with the collodion used in the old wet-plate process. When dry the paint forms a some-



Tungsten filament. Ordinary plate. Positive (reversal).



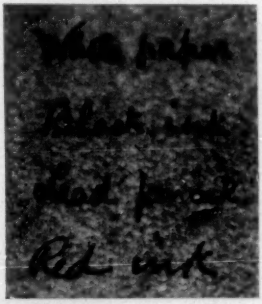
Tungsten filament. "Hydra" plate. Positive (no reversal).

what granular, slightly cream-colored film, which will emit for some time a soft, bluish light after a few seconds' exposure to any ordinary source of light; but the most satisfactory results are obtained from sunlight and arc light. Incandescent electric lights, even powerful tungsten lamps, are somewhat slow in action.

Many interesting experiments may be performed with the coated plates. If a piece of ordinary blue and ordinary red glass are placed upon a luminous-paint surface and then exposed to the direct light of an arc lamp for about half a minute, it will be found that under the blue glass a strong luminosity is developed, but under the red glass almost no effect is produced. A still more

curious effect is that if the entire surface of a coated plate is made luminous and then a portion covered with red glass and again exposed to the light, that part under the red will rapidly lose luminosity. The effect may be also shown by covering a portion of the luminous surface with opaque paper, and holding the plate near the red light of the dark room. A rapid falling off in luminosity will occur over the surface illuminated by the red rays. I do not mean that the luminosity merely appears less in the red light, but it is actually diminished.

Luminous paint may find a practical value in some copying work. Ordinary paper is moderately transparent to it, but writing



Relative opacity of common writing materials to rays from luminous paint.

and printing inks are rather opaque. If, therefore, we render a plate luminous, place it beneath a written or printed page, and lay a sensitive plate upon the page (these operations being, of course, carried out in the dark), it will be found that an exposure of ten or fifteen minutes will suffice to make a latent image on the sensitive plate which can be developed in the usual way. Experiments with gelatins colored with artificial colors have shown that the rays from luminous paint pass freely through violet and blue films, but scarcely at all through green and red films, and therefore no great difference is noted in the negative obtained when such screens are used with ordinary and with panchromatic plates. The panchromatic plates furnished by the Paget Company, which cannot be developed in red light, and the common lantern slide plates,

which may be used freely in red light, gave nearly the same negatives. A Lumière color-plate was also tried; it was found that no appreciable effect was obtained through the green and red films.

So far as I have experimented, the emanation from luminous paints goes equally through glass, quartz, thin films of celluloid, gelatin, barite, calcite, and kyanite, but this phase of the problem is still under investigation. A photographic novelty of practical value is the Paget "Hydra" plate. The emulsion of this contains some hydrazin sulphate, a synthetic product which materially controls over-exposure. I have made tests of the plates by exposing them to the light of a 60-watt tungsten within a few inches of the camera for ten minutes. This is sufficient to produce complete reversal, by over-exposure, in an ordinary plate, but reversal did not occur with "Hydra" plate. Several important uses of such a plate will occur to practical photographers.

Precipitation of Gold and Silver from Cyanide Solutions. H. A. MEGRAW. (*Eng. and Min. J.*, xcvii, 1232.)—The solution to be precipitated should be quite clear. Four precipitants are used: the electric current, charcoal, aluminum, and zinc. *Electrolysis* was employed in South Africa for several years. Iron anodes and lead cathodes were used, the deposited metal being stripped off the latter from time to time. By using relatively high current density the metal is precipitated as a sludge or slime which can be wiped from the cathode. Electrolysis regenerates an appreciable amount of cyanide, but the precipitate is hard to melt and contains all the metals taken up by the cyanide liquor. The use of *charcoal* is restricted. That made from soft wood is most efficient; 100 pounds of charcoal, twice re-burned, will carry 30 to 40 ounces of metal, and the ash is easily melted into bullion. The action of charcoal is probably due to occluded gases. *Aluminum* has been introduced recently in several mills. It does not combine with the cyanide as zinc does, and thus re-generates a certain quantity of the salt. *Zinc* is the most generally used precipitant, either as shavings or, better, as dust. A slight excess of cyanide must be present to prevent the precipitation of zinc hydroxide. In cyaniding old amalgamation tailings mercury is dissolved to a large extent and almost entirely precipitated by zinc; it may be recovered by retorting the precipitate. Zinc shavings are usually screened in recovering the values, so as to remove the coarse metal which is returned to the precipitation boxes. The fine portion, 60- to 80-mesh, is generally treated with acid, the residue constituting high-grade material, which is added to the undersize from the finer screens. Zinc dust precipitate only requires filter-pressing before melting down.

Magnesia and Dolomite Portland Cements and Their Properties. M. V. GLASENAPP. (*Chem. Zeit.*, xxxviii, 589.)—The calcium oxide in Portland cement was replaced by an equivalent quantity of magnesium oxide; the clinker then contained 59 per cent. MgO and 41 per cent. silicate. To effect solution of the magnesia in the silicate a much higher temperature (1700° to 1800° C.) was required than in the case of ordinary Portland cement. The magnesia cement only reacted with water after six to eight months, crystals, apparently of magnesium hydroxide, then being discernible. No gel formation could be detected in this period. The dolomite cement prepared from normal dolomite required a temperature of 1600° C. It was but little affected by water and the magnesia prevented the separation of calcium hydrosilicate crystals. The use of magnesia as a substitute for calcium oxide is thus impracticable, although there is a possibility that ignited magnesite might be added to Portland cement without injurious effect; since, although the magnesia combined with silica is hydraulically inactive, caustic magnesia in the form of a very fine powder slowly hardens into monoliths of great stability. The higher the temperature of burning the more slowly does the magnesia harden.

The Hardness of Iron—Carbon Alloys. R. VONDRÁČEK. (*Int. Zeits. Metallog.*, vi, 172.)—Andrew's theory that the hardness of quenched steels is due to the presence of finely divided cementite embedded in a ground mass of austenite and α-iron is not in accord with the law that the hardness of such alloys is the mean of the corresponding hardness values of the components, nor with the results of the author's experiments on the electrical conductivity of hardened steels. The total carbon in quenched steels is practically all in solution, and the theory is advanced that the hardness is a particular function of the transformation, and is due to the breaking up of the metal, as it were, during re-crystallization. In this respect there is no essential difference between iron alloys and bronzes. It is deduced, from the resistance of hypoeutectoid steels, that the ferrite which they contain has an appreciable carbon content, which increases as the total carbon increases. Eutectoid ferrite probably contains from 0.06 to 0.07 per cent. carbon, and with falling temperature the carbon content rises to a maximum of 0.14 per cent.

Absorption of Nitrogen by Calcium. R. BRANDT. (*Z. Angew. Chem.*, xxvii, 424.)—Calcium, in pieces weighing 3 to 5 grammes, is completely converted into Ca_3N_2 on heating to 400° to 500°C. in nitrogen. The pieces retain their form. The speed of the reaction increases from 300° to 440°C., then decreases, and is zero at about 800°C., the melting-point of calcium. Above this temperature the speed again rises to a considerable value.

THE THUNDERSTORM AND ITS PHENOMENA.*

BY

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The downrush of air clearly produces a vertically directed pressure on the surface of the earth, in the same manner that a horizontal flow produces a horizontally directed pressure against the side of a house. But a pressure equal to that given by 2 mm. of mercury, a pressure increase frequently reached in a thunderstorm, would mean about 2.72 grammes per square centimetre, or 27.2 kilogrammes per square metre, and require a wind velocity of roughly 50 kilometres per hour or 14 metres per second. Now, the velocity of the downrush of air in a thunderstorm is not at all accurately known, but while at times probably very considerable, the above value of 14 metres per second seems to be excessive; in fact, its average value may not be even half so great. If in reality it is not, then, since the pressure of a wind varies as the square of its velocity, it follows that less than one-fourth of the actual pressure increase can be caused in this way. Hence it would seem that there probably is at least one other pressure factor, and, indeed, such a factor obviously exists in the check to the horizontal flow caused by vertical convection.

To make this point clear: Assume two layers of air, an upper and a lower, flowing parallel to each other. Let their respective masses per unit length in the direction of their horizontal movement be M and m, and their velocities V and v. Now, if, through convection, say, the whole or any portion of the lower layer is carried aloft, obviously it must be replaced below by an equal amount of the upper layer.

Let the whole of the lower layer be carried up. This layer, to produce the rain that was above assumed, 2 centimetres, will have to be at least 1 kilometre deep, and if it should merely change places with the upper air, or if the different layers should mingle and assume a common velocity, V', there obviously would be no

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Concluded from page 560 of November issue.

change in the total linear momentum, nor in the flow. In symbols we would have the equation

$$MV + mv = (M + m)\, V'.$$

Mere mingling, therefore, of the two air currents, upper and lower, cannot change the depth of the atmosphere, nor, therefore, the height of the barometer. But then in the case of atmospheric convection we have something more than the simple mingling of two air currents, and the linear momentum does not, in general, remain constant. The increased surface velocity following convection, a phenomenon very marked in the case of a thunderstorm, causes an increased frictional drag and therefore a greater or less decrease in the total flow. Suppose this amounts to the equivalent of reducing the velocity of a layer of air only 25 metres thick from V to v, and let $V = 5v$. That is, the one three hundred and twentieth part of the atmosphere has its flow reduced to one-fifth its former value. This would reduce the total flow by about 1 part in 400, and thereby increase the barometric reading by nearly 2 millimetres.

It would seem, then, that the friction of the thunderstorm gust on the surface of the earth, through the consequent decrease in the total linear momentum of the atmosphere and, therefore, its total flow, must be an important contributing cause of the rapid and marked increase of the barometric pressure that accompanies the onset of a heavy thunderstorm.

To sum up: The chief factors contributing to the increase of the barometric pressure during a thunderstorm appear to be, possibly in the order of their magnitude: (*a*) Decrease of horizontal flow, due to surface friction. (*b*) Vertical wind pressure, due to descending air. (*c*) Lower temperature. (*d*) Decrease in absolute humidity.

Thunderstorm Temperatures.—Before the onset of the storm the temperature commonly is high, but it begins rapidly to fall with the first outward gust and soon drops often as much as 5° C. to 10° C. because, as already explained, this gust is a portion of the descending air cooled by the cold rain and by its evaporation. As the storm passes the temperature generally recovers somewhat, though it seldom regains its original value.

Thunderstorm Humidity.—As previously explained, heavy rain, at least up in the clouds, and therefore much humidity, and

a temperature contrast sufficient to produce rapid vertical convection, are essential to the genesis of a thunderstorm. Hence during the early forenoon of a thunderstorm day both the absolute and the relative humidity are likely to be high. Just before the storm, however, when the temperature has greatly increased, though the absolute humidity still is high, the relative humidity is likely to be rather low. On the other hand, during and immediately after the storm, because chiefly of the decrease in temperature, the absolute humidity is comparatively low and the relative humidity high.

"Rain-gush."—It has frequently been noted that the rainfall is greatest after heavy claps of thunder, a fact that appears to have given much comfort and great encouragement to those who maintain the efficacy of mere noise to induce precipitation—to jostle cloud particles together into raindrops. The correct explanation, however, of this phenomenon seems obvious: The violent turmoil and spasmodic movements within a large cumulus or thunderstorm cloud cause similar irregularities in the condensation and resulting number of raindrops at any given level. These in turn, as broken by the air currents, give local excess of electrification and of electric discharge or lightning flash. We have, then, starting toward the earth at the same time and from practically the same level, mass, sound, and light. The light travels with the greatest velocity, about 300,000 kilometres per second, and therefore the lightning flash is seen before the thunder is heard; its velocity being, roughly, only 330 metres per second. But the rain falls much slower still and therefore reaches the ground after the thunder is heard. In reality it is the excessive condensation or rain formation up in the cumulus cloud that causes the vivid lightning and the heavy thunder. According only to the order in which their several velocities cause them to reach the surface of the earth it might appear, and has often been so interpreted, that the lightning, first perceived, was the cause of the thunder, which, indeed, it is, and that the heavy thunder, next in order, was the cause of the excessive rain, which most certainly it is not.

Thunderstorm Velocity.—The velocity of the thunderstorm is simply the velocity of the atmosphere in which the bulk of the cumulus cloud happens to be located. Hence as the wind at this level is faster by night than by day and faster over the ocean

than over land, it follows that exactly the same relations hold for the thunderstorm, that it travels faster over water than over land and faster by night than by day. The actual velocity of the thunderstorm, of course, varies greatly, but its average velocity in Europe is 30 to 50 kilometres per hour; in the United States, 50 to 65 kilometres per hour.

Hail.—Hail, consisting of lumps of roughly concentric layers of compact snow and solid ice, is a conspicuous and well-known phenomenon that occurs during the early portion of most severe thunderstorms. But in what portion of the cloud it is formed and by what process the layers of ice and snow are built up are facts that, far from being obvious, become clear only when the mechanism of the storm itself is understood.

As before, let the surface temperature be 30° C. and the absolute humidity 40 per cent., or the dew point 15° C. Under these conditions saturation will obtain, and, therefore, cloud formation will begin when the surface air has risen to an elevation of 1.5 kilometres. Immediately above this level the latent heat of condensation reduces the rate of temperature decrease with elevation to about half its former value, nor does this rate rapidly increase with further gain of height. Hence, usually, for the above assumptions correspond in general to average thunderstorm conditions, it is only beyond the 4-kilometre level that freezing temperatures are reached. It is therefore only in the upper portions of cumulus clouds, the portions that clearly must consist of snow particles and undercooled fog or cloud droplets, that hail can either originate or greatly grow.

But what, then, is the process by which the nucleus of the hailstone is formed and its layer upon layer of snow and ice built up? Obviously such drops of rain as the strong updraft within the cloud may blow into the region of freezing temperatures will quickly congeal and also gather coatings of snow and frost. After a time each incipient hailstone will get into a weaker updraft, for this is always irregular and puffy, or else will tumble to the edge of the ascending column. In either case it will then fall back into the region of liquid drops, where it will gather a coating of water, a portion of which will at once be frozen by the low temperature of the kernel. But again it meets an upward gust, or falls back where the ascending draft is stronger, and again the cyclic journey from realm of rain to region of snow is begun;

and each time—there may be several—the journey is completed a new layer of ice and a fresh layer of snow are added. In general the size of the hailstones will be roughly proportioned to the strength of the convection current, but since their weights vary approximately (they are not homogeneous) as the cube of their diameters while the supporting force of the upward air current varies, also approximately, as only the square of their diameters it follows that a limiting size is quickly reached. It is also evident, from the fact that a strong convection current is essential to the formation of hail, that it can occur only where this convection exists, that is, in the front portion of a heavy to violent thunderstorm.

Some meteorologists hold that the roll scud between the ascending warm and descending cold air is the seat of hail formation, but this is a mistaken assumption. Centrifugal force would throw a solid object, like a hailstone, out of this roll probably before a single turn had been completed. Besides, and this objection is, perhaps, more obviously fatal than the one just given, the temperature of the roll scud, because of its position, the lowest of the whole storm cloud, clearly must be many degrees above the freezing point. Indeed, as the above calculation shows, temperatures low enough for the formation of hail cannot often obtain at levels much less than three times that of the scud, and therefore it clearly is in the higher levels of the cumulus and not in the low scud that hail must have its genesis and make its growth.

Lightning.—About the middle of the eighteenth century Franklin and others clearly demonstrated that the lightning of a thunderstorm and the discharge of an ordinary electric machine are identical in nature, and thereby established the fact that many of the properties of the former may logically be inferred from laboratory experiments with the latter. There is, however, one important source of difference between the two phenomena that does not seem always to be clearly kept in mind, namely, the distribution of the charge. In the one case, that of the laboratory experiment, the charge commonly exists almost wholly on the surface of the apparatus used, while in the other, that of the thunderstorm, it is irregularly distributed throughout the great cloud volume. Hence the two discharges, lightning and laboratory sparks, necessarily differ from each other in important details.

Nevertheless in each case the atmosphere must be ionized before the discharge can take place freely, and this condition seems, at times at least, to establish itself progresso-spasmodically. That is, a small initial discharge, losing itself in a terminal brush, is rapidly followed by another and another, each losing itself in a manner similar to the first, until a path from pole to pole is sufficiently ionized to permit of a free flow and quick exhaustion of the remaining charge. Fig. 23, copied from a photograph obtained by Walter,[9] on a rapidly moving plate, shows how a laboratory spark spasmodically (doubtless at the period of electrical oscillation) ionizes the air from either pole and thus progressively extends and finally closes the conducting path of complete discharge. There appears also to be good evidence that the

FIG. 23.

The growth of an electric spark discharge (Walter).

lightning discharge often builds itself up in a manner generally similar, though, perhaps, radically different, in certain details. As already implied, ordinary laboratory apparatus has a free period of electrical oscillation, and therefore an electrical discharge from such apparatus is oscillatory in nature, but as yet there seems to be no certain evidence that lightning discharges ever are distinctly oscillatory. They frequently are pulsatory, discharge after discharge taking place in the same direction and along the same path, as we shall see later; but this is an entirely different thing from being oscillatory, or consisting of a decreasing series the units of which are alternately in opposite directions.

It will be convenient, in further discussing the facts known about lightning, to classify it according to its general appearance.

Streak Lightning.—When the storm is close by, the lightning discharge almost invariably appears to the unaided eye as one or more sinuous lines or streaks of vivid white or pink. Sinuous,

because electrically the atmosphere is heterogeneous or unequally ionized. There often appears to be a main trunk with a number of branches, all occurring at the same time and instantaneously. At other times there seem to be two or more simultaneous but locally disconnected streaks. Frequently the discharge continues flickeringly (on rare occasions even steady, like a white-hot wire) during a perceptible time—occasionally a full second.

But all these phenomena are best studied by means of the camera, and have been so studied by several persons, among whom Walter, of Hamburg, and Larsen, of Chicago, are two of the

FIG. 24.

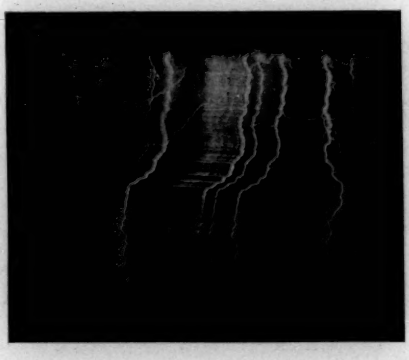
Streak lightning, stationary camera; companion to Fig. 25 (Walter).

most persistent and successful. Stationary cameras, revolving cameras, stereoscopic cameras, cameras with revolving plates, and cameras with spectrographic attachments have all been used, separately and jointly, and the results have abundantly justified the time and the labor devoted to the work.

Fig. 24, copied by permission from one of Walter's unpublished negatives, shows the ordinary tracery of a lightning discharge when photographed with a stationary camera. It is only a permanent record of the appearance of the lightning to the unaided eye. Fig. 25, however, also copied by Walter's kind permission from one of his unpublished photographs, is a record of the same discharge obtained with a rotating camera. It will be noted that the more nearly vertical discharge occurred but once,

or was single; that this discharge was quickly followed by a second along the same path to about one-fourth of the way to the earth where it branched off on a new course; that the second discharge was followed in turn at short but irregular intervals by a whole series of sequent discharges; that most of the discharges appeared as narrow, intensely luminous streaks, and that one of the sequent discharges appeared, not to the eye, but on the plate of the rotating camera, as a broad band or ribbon. On close inspection it will be obvious that the plaid-like ribbon effect is due, the warp to irregularities in the more or less continuous discharge, and the

FIG. 25.



Streak lightning (sequent discharges), rotating camera; companion to Fig. 24 (Walter).

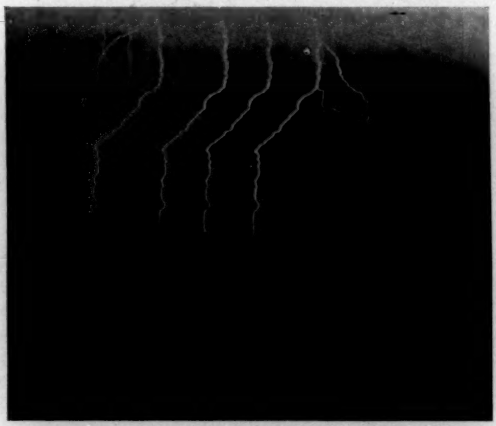
woof to roughly end-on and therefore brighter portions of the streak. Another point particularly worthy of attention is the fact that while the first discharge has several side branches the following ones remain entire from end to end and are nowhere subdivided.

Fig. 26, taken from a photograph obtained by Mr. Larsen, of Chicago, and kindly loaned for use here by the Smithsonian Institution, shows another series of sequent discharges similar to those of Fig. 25, except that in this case there was no ribbon discharge. The time of the whole discharge, as calculated by Mr. Larsen, was 0.315 second. Here, too, side branches occur with the first, but only the first, discharge. This, however, is not

an invariable rule for occasionally, as illustrated by Fig. 27, copied from a published photograph by Walter, the side branches persist through two or three of the first successive discharges, but not through all. In such case each tributary when repeated follows, as does the main stream, its own original channel.

The phenomenon of sequent discharges, all along the same path, and the disappearance of the side branches with or quickly after the first discharge both seem reasonably clear. The first

FIG. 26.

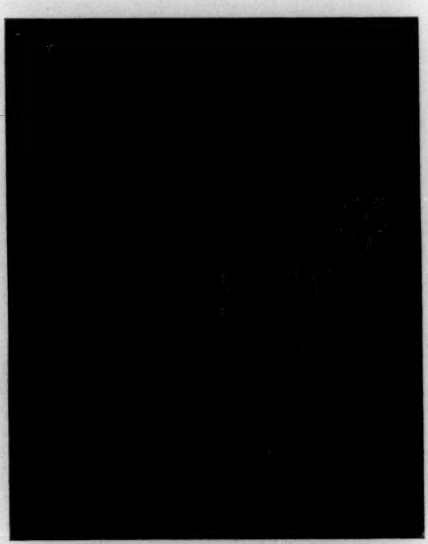


Streak lightning (sequent discharges), rotating camera (Larsen).

discharge, however produced, obviously takes place against very great resistance, and therefore under conditions the most favorable for the occurrence of side branches or ramifications. But the discharge itself leaves the air along its path temporarily highly ionized—puts a temporary line conductor, with here and there a poorer conducting branch, in the atmosphere. This conductor is not only temporary (half the ions are reunited in about 0.15 second, the air being dusty) but also so extremely fragile as to be liable to rupture by the atmospheric violence it itself creates. Because partly, perhaps, of just such interruptions, and because

also of the volume distribution of the electricity which prevents a sudden and complete discharge, the actual discharge is divided into a number of partials that occur sequently. Obviously the breaks in the conducting (ionized) path, if they exist, are only here and there and but little more than sufficient to interrupt the flow. Hence the next discharge, if it occurs quickly, must follow

FIG. 27.



Streak lightning (sequent discharges), rotating camera (Walter).

the conducting and, therefore, original discharge path. Besides, in the subsequent discharges the original side branches will be quickly abandoned because of their greater resistance, or, what comes to the same thing, because of the more abundant ionization and consequent higher conductivity of the path of heaviest discharge.

This leaves the genesis of the initial discharge, often if not usually the only one, to be explained, and indeed this probably

is, at present, the least understood of all the many thunderstorm phenomena. Judging from the voltages required to produce laboratory sparks, roughly 30,000 volts per centimetre, it is not obvious how such tremendous voltage differences can be established between clouds or between a cloud and the earth as would seem to be necessary to produce a discharge kilometres in length, as often occurs. Of course the potential of individual drops may grow in either of two ways: (*a*) By coalescence of equally charged smaller drops into larger ones. In this case, since capacity is directly proportioned to the radius, the potentials of the individual drops must be proportional to the squares of their radii. (*b*) By evaporation of equally charged drops. Here the potentials of the individual drops obviously are inversely proportional to their radii. In each case the tendency of the separate drops to discharge is increased, but the potential of the cloud as a whole remains unchanged. At present, therefore, one can do but little more than speculate on the subject of the primary lightning discharge, but even that much may be worth while since it helps one to remember the facts.

As already explained the electrical separation within a thunderstorm cloud is such as to place a heavily charged positive layer (lower portion of the cloud) between the earth and a much higher, also heavily charged, negative layer (upper portion of the cloud). Hence the discharges, or lightning, from the intermediate or positively charged layer may be either to the negative portion above, in some cases even to an entirely different cloud, or to the earth below. Further, through the sustaining influence and turbulence of the uprushing air, there must be formed at times and places practically continuous sheets and streams of water, of course heavily charged and at high potential, and also layers and streaks of highly ionized air; that is, electrically speaking, heavily charged conducting sheets and rods, whether of coalesced drops or of ionized air, are over and over, so long as the storm lasts, momentarily placed here and there within the positively charged mass of the storm cloud.

Let us see, then, what might be expected as the result of this peculiar disposition of charges and conductors, the result, namely, of the existence of a heavily surface-charged vertical conductor in a strongly volume-charged horizontal layer or region, above and

below which there are steep potential gradients to negatively charged parallel surfaces.

The conductor will be at the same potential throughout, and therefore the maxima of potential gradients normal to it will be at its ends, where, if these gradients are steep enough, and the longer the conductor the steeper the gradients, brush discharges will take place. Assume, then, that a brush discharge does take place and that there is a supply of electricity flowing into the conductor to make good the loss. The brush and the line of its most vigorous ionization necessarily will be directed along the potential gradient or toward the surface of opposite charge. But this very ionization automatically increases the length of the conductor, for a path of highly ionized air is a conductor, and as the length of the conductor grows so, too, does the steepness of the potential gradient at its forward or terminal end, and as the steepness of this gradient increases the more vigorous the discharge, always assuming an abundant electrical supply. Hence, an electric spark once started within a thunderstorm cloud has a good chance, by making its own conductor as it goes, of geometrically growing into a lightning flash of large dimensions. Of course when the electrical supply is small the lightning is feeble and soon dissipated.

Whether the discharge actually does burrow its way through the atmosphere in some such manner as that indicated probably would be difficult, though not necessarily impossible, of observation. Indeed, a roughly analogous phenomenon [10] can be produced on a photographic plate by bringing in contact with the film, some distance apart, two conducting points attached to the opposite poles of an influence machine. Brush discharges develop about each point, but the glow at the negative pole detaches itself and slowly meanders across the plate toward the positive point. As it goes it continually builds for itself, out of the silver of the emulsion, a conducting path.

Rocket Lightning.—Many persons have observed what at least seemed to be a progressive growth in the length of a streak of lightning. In some cases [11] this growth or progression has appeared so slow as actually to suggest the flight of a rocket, hence the name.

At first one might well feel disposed to regard the phenomenon in question as illusory, but it has been too definitely described and too frequently observed to justify such summary dismissal.

Naturally, in the course of thousands of lightning discharges, many degrees of ionization, availability of electrical charge, and slopes of potential gradient are encountered. Ordinarily the growth of the discharge, doubtless, is in a geometric ratio and the progress of its end exceedingly swift, but it seems possible for the conditions to be such that the discharge can barely more than sustain itself, in which case the movement of the flash terminal may, possibly, be relatively slow.

Ball Lightning.—Curious luminous balls or masses, of which C. de Jans [12] probably has given the fullest account, have time and again been reported among the phenomena observed during a thunderstorm. Most of them appear to last only a second or two and to have been seen at close range, some even passing through a house, but they have also appeared to fall, as would a stone,[13] or like a meteor, from the storm cloud, and along the approximate path of both previous and subsequent lightning flashes. Others appear to start from a cloud and then quickly return, and so on through an endless variety of places and conditions.

Doubtless many reported cases of ball lightning are entirely spurious, being either fixed or wandering brush discharges or else nothing other than optical illusions, due in most cases probably to persistence of vision. But here, too, as in the case of rocket lightning, the amount and excellence of observational evidence forbid the assumption that all such phenomena are merely subjective. Possibly in some instances, especially those in which it is seen to fall from the clouds, ball lightning may be only extreme cases of rocket lightning, cases in which the discharge for a time just sustains itself. A closely similar idea has been developed in detail by Toepler.[14] It may either disappear wholly and noiselessly, as often reported, or it could perhaps suddenly gain in strength and instantly disappear, as sometimes observed, with a sharp abrupt clap of thunder.

To say that all genuine cases of ball lightning, those that are not mere optical illusions, are stalled thunderbolts, certainly may sound very strange. But that indeed is just what they are according to the above speculation, a speculation that recognizes no difference in kind between streak, rocket, and ball lightning, only differences in the amounts of ionization, quantities of available electricity and steepness of potential gradients.

Sheet Lightning.—When a distant thundercloud is observed

at night one is quite certain to see in it beautiful illuminations, looking like great sheets of flame, that often flicker and glow in exactly the same manner as does streak lightning for well-nigh a whole second. In the daytime and in full sunlight the phenomenon when seen at all appears like a sudden sheen that travels and spreads here and there over the surface of the cloud. Certainly in most cases, so far as definitely known in all cases, this is only reflection from the body of the cloud of streak lightning in other and invisible portions. Conceivably a brush or coronal discharge may take place from the upper surface of a thunderstorm cloud, but one would expect this to be either a faint continuous glow or else a momentary flash coincident with a discharge from the lower portion of the cloud to earth or to some other cloud. But, as already stated, only reflection is definitely known to be the cause of sheet lightning. Coronal effects seem occasionally possible, but that they are ever the cause of the phenomenon in question has never clearly been established and appears very doubtful. It has often been asserted, too, that there is a radical difference between the spectra of streak and sheet lightning, but even this does not appear ever to have been photographically proved.

Beaded Lightning.—Discontinuous or beaded streaks of lightning have been reported from time to time. Indeed the author himself has several times seen, or had the impression of seeing, this phenomenon, but with one or two doubtful exceptions he felt practically certain that it was only an optical illusion. In addition to visual observations of the kind just described many photographs showing streaks of light broken into more or less evenly spaced dashes have been obtained and reported as photographs of beaded lightning. Without exception, however, these seem certainly to be nothing other than the photographs of alternating current electric lights, taken with the camera in motion. The objective reality, therefore, of beaded lightning does not seem at all well established, at least not sufficiently well to justify any serious effort to explain it.

Return Lightning.—This is commonly referred to as the return shock, and is only those relatively small electrical discharges that take place here and there from objects on the surface of the earth coincidently with lightning flashes, and as a result of the suddenly changed electrical strain. These dis-

charges are always small in comparison with the main lightning flash, but at times are sufficient to induce explosions, to start fires, and even to take life.

Dark Lightning.—When a photographic plate is exposed to a succession of lightning flashes, it occasionally happens that one or more of the streak images, on development, exhibits the "Clayden effect"—that is, appears completely reversed—while the others show no such tendency. Obviously, then, on prints from such a negative the reversed streaks must appear as dark lines, and for that reason the lightning flashes that produced them have been called "dark lightning." There is, of course, no such thing as dark lightning, but the photographic phenomenon that gave rise to the name is real, interesting, and reproducible at will in the laboratory.[15]

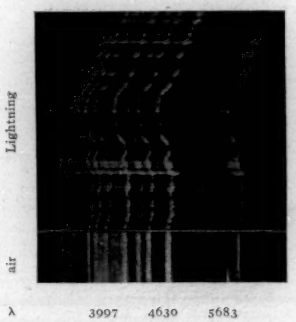
Temperature.—What the temperature along the path of a lightning discharge is no one knows, but it obviously is high, since it frequently sets fire to buildings, trees, and many other objects struck. In an ordinary electrical conductor the amount of heat generated in a given time by an electric current is proportional to the product C^2RT, in which C is the strength of the current, R the ohmic resistance, and T the time in question during which C and R are supposed to remain constant. In a spark discharge of the nature of lightning some of the energy produces effects, such as decomposition and ionization, other than mere local heating, but as experiment shows, a great deal of heat is generated, according, so far as we know, to the same laws that obtain for ordinary conductors. Hence extra heavy discharges, like extra large currents, produce excessive heating, and therefore are far more liable than are light ones to set on fire any objects that they may hit.

Visibility.—Just how a lightning discharge renders the atmosphere through which it passes luminous is not definitely known. It must and does make the air path very hot, as we have seen, but no one has yet succeeded, by any amount of ordinary heating, in rendering either oxygen or nitrogen luminous. Hence it seems well nigh certain that the light of lightning flashes owes its origin to something other than high temperature, probably to internal atomic disturbances induced by the swiftly moving electrons of the discharge.

Spectrum.—Lightning flashes are of two colors, white and

pink or rose. The rose-colored flashes, when examined in the spectroscope, show several lines due to hydrogen which, of course, is furnished by the decomposition of some of the water along the lightning path. The white flashes, on the other hand, show no hydrogen lines or, at most, but faint ones. As one might suspect, the spectrum of a lightning flash and that of an ordinary electric spark in air are practically identical. This is well shown by Fig. 28, copied from an article on the spectrum of lightning by Fox,[16] in which the upper or wavy portion is due to the lightning and the lower or straight portion to a laboratory spark in air.

FIG. 28.



It is often asserted that the spectrum of streak lightning consists wholly of bright lines and that sheet lightning gives only nitrogen bands; and from this it is argued that the latter is not a mere reflection of the first. This assertion is not supported by Fig. 28, the brightest portions of which, the portions that would the longest be seen as reflection grew steadily feebler, coincide with strong nitrogen bands. In this connection, however, it should be remembered that accurate wave-length measurements, and therefore positive identification of the lines of lightning spectra, is not possible, owing to the small dispersion or separation of the lines on all such negatives so far reported.

Duration.—The duration of the lightning discharge is exceedingly variable, ranging from 0.0002 second for a single flash to, in rare cases, even a full second or more for a multiple flash

consisting of a primary and a series of sequent flashes. On rare occasions a discharge of long duration appears *to the eye* to be steady like a glowing solid. Possibly the best measurements of the shorter intervals were made by De Blois [17] with the aid of a high-frequency oscillograph. He found the durations of 38 single peaks, averaging 0.00065 second, to range from 0.0002 second to 0.0016 second. Flashes that last as long as a few tenths or even a few hundredths of a second are almost certainly multiple, consisting of a succession of apparently individual discharges occurring at unequal intervals. Occasionally a practically continuous discharge of varying intensity, but all the time strong enough to produce luminosity, will last a few hundredths of a second.

It must be remembered that the duration of even a single discharge and the length of time to complete the circuit, or ionize a path, from cloud to earth, say, are entirely different things. The latter seems usually (rocket and ball lightning may furnish exceptions) to be of exceedingly short duration, while the former depends upon the supply of electricity and the ohmic resistance directly and upon the potential difference inversely.

Discharges Direct, not Alternating.—Years ago some one for some reason or other, or for no reason, made the statement that the lightning flash is alternating and of high frequency, like the discharge of a Leyden jar, and forthwith, despite the fact that all evidence is to the contrary, it became a favorite dogma of the text-book, passed on unquestioned from author to author and handed down inviolate from edition to edition. There often are a number of successive discharges in a fraction of a second, as photographs taken with a revolving camera show, but they are not only along the same path but also in the same direction. This is obvious from the fact that when the side branches persist, as in Fig. 26, through two or more partial or sequent discharges, they are always turned in the same direction. It is also proved by the direct evidence of the oscillograph.[18]

In the case of each separate discharge also the direction seems constant. It may vary in strength, or pulsate, but, apparently, it does not alternate. There are several reasons for concluding that lightning discharges are direct and not alternating, of which the following cover a wide range and probably are the best:

(*a*) Lightning operates telegraph instruments. If the discharge were alternating it would not do so.

(*b*) At times it reverses the polarity of dynamos. This requires a direct and not a high-frequency alternating discharge.

(*c*) The oscillograph [19] shows each surge or pulsation, as well as the whole flash, to be unidirectional.

(*d*) The relative values of the ohmic resistance, the self-induction, and the capacity, in the case of a lightning discharge, appear usually, if not always, to be such as to forbid the possibility of oscillations.

It has been shown that whenever the product of the capacity by the square of the resistance is greater than four times the self-induction, or, in symbols, that whenever

$$CR^2 > 4L$$

oscillations are impossible. Undoubtedly all these terms vary greatly in the case of lightning discharges, but R, presumably, is always sufficiently large to maintain the above inequality and therefore absolutely to prevent oscillations.

Possibly a calculation giving roughly the numerical order of the terms involved would be helpful. For this purpose assume a cloud whose undersurface is circular with a radius of 3 kilometres, and whose height above the ground is 1 kilometre, and let there be a discharge from the centre of the cloud base straight to the earth: Find a probable value for the self-induction and capacity, and from these the limiting value of the resistance to prevent oscillations, or the value of R in the equation

$$CR^2 = 4L.$$

To find L we have the fact that the coefficient of self-induction is numerically equal to twice the energy in the magnetic field per unit current in the circuit, and the further fact that per unit volume this energy is numerically equal to $H/8\pi$, in which H is the magnetic force. Let a be the radius of the lightning path and assume the current density in it to be uniform. Let b be the equivalent radius of the cylinder, concentric with the lightning path, along which the return or displacement current flows. In this case the energy W of the magnetic field per centimetre length of the discharge is given by the equation

$$W = \log_e \frac{b}{a} + \frac{1}{2}.$$

Let $b = 2$ kilometres and $a = 5$ centimetres. Then $W = \log_e 4 \times 10^4 + \frac{1}{2} = 11$, approximately. Hence the energy of the magnetic field per unit current for the whole length, 1 kilometre, of the flash is represented by the equation

$$W10^5 = 11 \times 10^5,$$

hence the self-induction $= 22 \times 10^5 = 22 \times 10^{-4}$ henry.

To find C we shall assume a uniform field between the cloud and the earth. As a matter of fact, this field is not uniform, and the calculated value of C, based upon the above assumption, is somewhat less than its actual value. Assuming, then, a uniform field we have

$$C = \frac{a}{4\pi d} = \frac{\pi 9 \times 10^{10}}{4\pi \times 10^5} = 225 \times 10^3 = 25 \times 10^{-6} \text{ farad, about.}$$

Hence, substituting in the equation

$$CR^2 = 4L,$$

we get

$$R = 190 \text{ ohms per kilometre, approximately.}$$

Neither a, the radius of the lightning path, nor b, the equivalent radius of the return current, is accurately known, but from the obviously large amount of suddenly expanded air necessary to produce the atmospheric disturbances incident to thunder it would seem that 1 centimetre would be the minimum value for a. Also, from the size of thunder clouds, it appears that 10 kilometres would be the maximum value for b.

On substituting these extreme values in the above equations, we get

$$R = 200 \text{ ohms per kilometre, roughly.}$$

From the fact that C varies inversely and L directly as the altitude of the cloud it follows that, other things remaining equal, the height of the cloud has no effect on the value of R per unit length.

If the altitude is kept constant and the size of the cloud varied C will increase directly as the area, and L will increase directly as the natural logarithm of the equivalent radius of the cylinder of return current. Assuming the area of the cloud base to be 1 square kilometre, which certainly is far less than the ordinary size, and computing as above we find

$$R = 850 \text{ ohms per kilometre, roughly.}$$

Again, assuming the base area to be 1000 square kilometres, an area far in excess of that of the base of an ordinary thunder-storm cloud, we find

$$R = 35 \text{ ohms per kilometre, roughly.}$$

It would seem, therefore, that a resistance along the lightning path of the order of 200 ohms per kilometre, or 0.002 ohm per centimetre, would suffice, in most cases, absolutely to prevent electrical oscillations between cloud and earth. In reality the total resistance includes, in addition to that upon which the above calculations are based, the resistance in parallel of the numerous feeders or branches within the cloud itself. In other words, the assumption that the resistance of the condenser plates is negligible may not be strictly true in the case of a cloud. Nor is this the only uncertainty, for no one knows what the resistance along the path of even the main discharge actually is; though, judging from the resistance of an oscillatory electric spark,[20] it, presumably, is much greater than the calculated limiting value; and if so, then lightning flashes, as we have seen, must be unidirectional and not alternating.

Length of Streak.—The total length of a streak of lightning varies greatly. Indeed the brush discharge so gradually merges into the spark and the spark into an unmistakable thunderbolt that it is not possible sharply to distinguish between them, nor, therefore, to set a minimum limit to the length of a lightning path. When the discharge is from cloud to earth the length of the path is seldom more than 2 to 3 kilometres, but, in the case of low-lying clouds, may be much less, and especially so when they envelop a mountain peak.

On the other hand, when the discharge is from cloud to cloud the path generally is far more tortuous and its total length much greater, amounting at times to 10, 15, and even 20 kilometres.

Discharge, Where to Where.—As already explained, lightning discharges may be from cloud to earth, from one part to another of the same cloud, or from cloud to cloud. But since the great amount of electrical separation, without which the lightning could not occur, takes place within the rain cloud, it follows that this is also likely to be the seat of the steepest potential gradients. Hence it would appear that lightning must occur most frequently between the lower and the upper portions

of the same cloud, and this is fully supported by observations. The next in frequency, especially in mountainous regions, is the discharge from cloud (lower portion) to earth, and the least frequent of all, ordinarily, those that take place between one and another entirely independent or disconnected clouds.

Explosive Effects.—The excessive and abrupt heating caused by the lightning current explosively and greatly expands the column of air through which it passes. It even explosively vaporizes such volatile objects as it may hit that have not sufficient conductivity to carry it off. Hence, chimneys are shattered, shingles torn off, trees stripped of their bark or utterly slivered and demolished, kite and other wire fused or volatilized, holes melted through steeple bells and other large pieces of metal, and a thousand other seeming freaks and vagaries wrought.

Many of the effects of lightning appear at first difficult to explain, but, except the physiological and, probably, some of the chemical, all depend upon the sudden and intense heating along its path.

Chemical Effects.—As is well known, oxides of nitrogen and even what might be termed the oxide of oxygen, or ozone, are produced along the path of an electric spark in the laboratory. Therefore one might expect an abundant formation, during a thunderstorm, of these same compounds. And this is exactly what does occur, as observation abundantly shows. It seems probable, too, that some ammonia must also be formed in this way, the hydrogen being supplied by the decomposition of raindrops and water vapor.

In the presence of water or water vapor these several compounds undergo important changes or combinations. The nitrogen peroxide (most stable of the oxides of nitrogen) combines with water to produce both nitric and nitrous acids; the ozone with water gives hydrogen peroxide and sets free oxygen; and the ammonia in the main merely dissolves, but probably also to some extent forms caustic ammonia and hydrogen. Symbolically the reactions seem to be as follows:

$$2NO_2 + H_2O = HNO_3 + HNO_2.$$
$$O_3 + H_2O = H_2O_2 + O_2.$$
$$2NH_3 + 2H_2O = 2NH_4OH + H_2.$$

The ammonia and also both the acids through the production of soluble salts are valuable fertilizers. Hence, wherever

the thunderstorm is frequent and severe, especially, therefore, within the tropics, the chemical actions of the lightning may materially add, as has recently been shown,[21] to the fertility of the soil and the growth of crops.

Danger.—It is impossible to say much of value about the danger from lightning. Generally it is safer to be indoors than out during a thunderstorm, especially if the house has a well-grounded metallic roof. If outdoors it is far better to be in a valley than on the ridge of a hill, and it is always dangerous to take shelter under a tree—the taller the tree, other things being equal, the greater the danger. Some varieties of trees appear to be more frequently struck, in proportion to their numbers and exposure, than others, but no tree is immune. It seems that, in general, the trees most likely to be struck are those that have either an extensive root system, like the locust, or deep tap roots, like the pine, and this for the very obvious reason that they are the best grounded and therefore offer, on the whole, the least electrical resistance.

Finally, if one has to be outdoors and exposed to the danger of a violent thunderstorm it is advisable, so far as danger from the lightning is concerned, to get soaking wet, because wet clothes are much better conductors, and dry ones poorer, than the human body. In extreme cases it might even be advisable to lie flat on the wet ground.

As just implied, the contour of the land is an important factor in determining the relative danger from lightning because, obviously, the chance of a cloud-to-earth discharge, the only kind that is dangerous, varies inversely as the distance between them. Hence thunderstorms are more dangerous in mountainous regions, at least in the higher portions, than over a level country. For this same reason also, distance of cloud to earth, there exists on high peaks a level or belt of maximum danger, the level, approximately of the base of the average cumulus cloud. The tops of the highest peaks are seldom struck, simply because the storm generally forms and runs its course at a lower level.

Clearly, too, for any given section the lower the cloud the greater the danger. Hence a high degree of humidity is favorable to a dangerous storm, partly because the clouds will form at a low level and partly because the precipitation will be abundant. Hence, too, a winter thunderstorm, because of its generally lower

clouds, is likely to be more dangerous than an equally heavy summer one.

The Ceraunograph.—Various instruments, based upon the principles of "wireless" receivers, have been devised for recording the occurrence of lightning discharges. Of course the sensitiveness of the instrument, the distance and the magnitude of the discharge all are factors that affect the record, but by keeping the sensitiveness constant, or nearly so, it is possible with an instrument of this kind to estimate the approximate distance, progress, and to some extent even the direction of the storm. Nevertheless there does not appear to be much demand for this information, and therefore at present the ceraunograph is but sparingly used.

Thunder.—For a long while no one had even a remotely satisfactory idea in regard to the cause of thunder, and it is not a rare thing even yet to hear such a childish explanation as that it is the noise caused by the bumping or rubbing of one cloud against another.

As above explained, because of the sudden and intense heating due to the lightning discharge the air column through which it passes is so greatly and so abruptly expanded as to simulate in every detail a violent explosion, and therefore to send out from every portion of its path a steep compression wave, which, of course, is the real physical cause of the thunder. The expansion, obviously, is followed by a cooling and contraction, but though this action is rapid it probably is not nearly rapid enough to have anything to do with the production of thunder, though many have suggested it as the whole cause.

Rumbling.—Probably the most distinctive characteristic of thunder is its long-continued rumbling and great variation in intensity. Several factors contribute to this peculiarity, among them:

Inequalities in the distances from the observer to the various portions of the lightning's path. Hence the sound, which ordinarily travels about 330 metres per second in the air, will not all reach him at the same time, but continuously over an appreciable interval of time.

Crookedness of path. Because of this condition it often happens that sections of the path here and there are, each through its length, at nearly the same distance from the observer or

follow roughly the circumferences of circles of which he is the centre, while other portions are directed more or less radially from him. This would account for, and doubtless in a measure is the correct explanation of, some of the loud booming effects or crashes that accompany thunder.

Succession of discharges. When, as often happens, several discharges follow each other in rapid succession there is every opportunity for all sorts of irregular mutual interference and reinforcement of the compression waves or sound impulses they send out.

Reflection. Under favorable conditions the echo of thunder from clouds, hills, and other reflecting objects certainly is effective in accentuating and prolonging the noise and rumble. But the importance of this factor generally is greatly overestimated, for ordinarily the rumble is substantially the same whether over the ocean, on the prairies, or among the mountains.

Distance Heard.—The distance to which thunder can be heard seldom exceeds 25 kilometres, while ordinarily, perhaps, it is not heard more than half so far. To most persons, familiar with the great distances to which the firing of large cannon is still perceptible, the relatively small distances to which thunder is audible is quite a surprise. It should be remembered, however, that both the origin of the sound and often the air itself as a sound conductor are radically different in the two cases. The firing of cannon or any other surface disturbance is heard farthest when the air is still and when, through inversion or otherwise, it is so stratified as in a measure to conserve the sound energy between horizontal planes. Conversely, sound is heard to the least distance when the atmosphere is irregular in respect to either its temperature or moisture distribution, or both, for these conditions favor the production of internal sound reflections and the dissipation of energy. Now the former or favorable conditions occasionally obtain during the production of ordinary noises, including the firing of cannon, but never obtain during a thunderstorm. In fact, the thunderstorm is especially likely itself to establish the second set of the above conditions, or those least favorable to the far carrying of sound.

Then, too, when a cannon, say, is fired the noise all starts from the same place, the energy is concentrated, while in the case of thunder it is stretched out over the entire length of the

lightning path. In the first case the energy is confined to a single shell; in the second it is diffused through an extensive volume. It is these differences in the concentration and the conservation of the energy that cause the cannon to be heard much farther than the heaviest thunder, even though the latter almost certainly produces much the greater total atmospheric disturbance.

Normal Atmospheric Electricity.—The only reason for mentioning normal atmospheric electricity in connection with thunderstorms is to emphasize the fact that, contrary to what many suppose to be the case, there is but little relation, in the sense of cause and effect, between these two phenomena. Thus while the difference in electrical potential between the surface of the earth and a point at constant elevation is roughly the same at all parts of the world, the number and intensity of thunderstorms vary greatly from place to place. Further, while the potential gradient at any given place is greatest in winter the number of thunderstorms is most frequent in summer, and while the gradient, in the lower layer of the atmosphere, at many places, usually is greatest from 8 to 10 o'clock, both morning and evening, and least at 2 to 3 o'clock P.M. and 3 to 4 o'clock A.M., no closely analogous relations hold for the thunderstorm.

Probably the most interesting conclusion in regard to normal atmospheric electricity so far drawn from observation and experiment is this: That the earth everywhere, land and water and from pole to pole, is a negatively charged sphere of practically constant surface density, surrounded by an atmosphere so conducting that it is constantly carrying away a current that amounts on the whole to about 1000 ampères.

Where the supply of negative electricity comes from that keeps the surface of the earth on the whole negatively charged in spite of this steady great loss, or how the outgoing current is compensated, no one knows. Rain does not help matters, for, as we have seen, that is prevailingly positive, whereas we need, to compensate the loss, to bring back negative electricity and a great deal of it. Neither, so far as known, is compensation supplied by means of the lightning, for, in the great majority of cases, this, too, is positive from cloud to earth. And so the puzzle remains. As Simpson[22] puts it:

"A flow of negative electricity takes place from the surface of the whole globe into the atmosphere above it, and this necessi-

tates a return current of more than 1000 ampères; yet not the slightest indication of any such current has so far been found, and no satisfactory explanation for its absence has been given."

Much more, of course, might be said on this subject, for it is a big one on which many have labored, but perhaps the above is sufficient for the purpose of this final section, namely, to show that, contrary to opinions often held, there is no obvious and close relation between the thunderstorm and normal atmospheric electricity; that, according to our best evidence, they are distinct and independent phenomena.

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The United States Bureau of Mines has begun the collection of a general library of petroleum literature, under the direction of W. A. Williams, chief petroleum technologist. The details of this work have been assigned to Dr. David T. Day, who has recently been transferred from the United States Geological Survey as petroleum technologist, and who will also assist in a thoroughly organized research into the chemistry of oils, which is being developed by the Bureau of Mines. The importance of such a library is so manifest that it is hoped all technologists will aid in the work by exchanging with the bureau all available books and maps on this subject.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A WHEATSTONE BRIDGE FOR RESISTANCE THERMOMETRY.

By C. W. Waidner, H. C. Dickinson, E. F. Mueller, and D. R. Harper 3rd.

[ABSTRACT.]

THE Wheatstone bridge described in this paper was designed with especial reference to flexibility of use in measurements with resistance thermometers. The bridge is adapted to use with either the Siemens type or Callendar type of resistance thermometer, or with the potential terminal type of thermometer by the use of the Thomson double bridge method. The instrument is also arranged so that it may be completely self-calibrated.

The 0.01, 0.001, and 0.0001 ohm decades are secured by varying, by means of dial switches, the shunts on three coils permanently connected in the measuring arm of the bridge. The sum of the resistances which are permanently connected is 2.5 ohms when the dials are set on zero, so that in order to measure resistances smaller than this a coil of 2.5 ohms is connected in the adjacent arm of the bridge.

The entire electrical circuit of the bridge, coils, contact blocks, switches, and connectors is totally immersed in an oil-bath thermostat, and special manipulating devices for the links and dials, etc., are provided. Details of construction are shown by photographs and briefly explained in the text.

A new form of hermetically sealed coil, suitable for Wheatstone bridges, potentiometers, and similar apparatus, is fully described and record of its performance reviewed. Such construction eliminates the seasonal variations of resistance (with varying atmospheric humidity) found in coils of the usual types.

The accuracy attainable with the bridge is such that resistances of one ohm or more can be measured to an accuracy of one part in 300,000 in terms of the unit in which the calibration is expressed. This corresponds to an accuracy of about 0.001° for measurements with the platinum resistance thermometer. Low resistances, the accuracy of measurement of which is limited by variations in contact resistances, may be measured to about three-millionths

* Communicated by the Bureau.

of an ohm. The small temperature changes of a few degrees, occurring in calorimetric measurements, may be measured to one or two parts in ten thousand.

THE TOTAL EMISSIVITY OF PLATINUM AND THE RELATION BETWEEN TOTAL EMISSIVITY AND RESISTIVITY.

By Paul D. Foote.

[ABSTRACT.]

THE theory of radiation from metals developed by Aschkinass has been extended and the following general equation has been derived for the total emissivity of a metal:

$$E = 0.5736\sqrt{rT} - 0.1769\,rT$$

where E is the total emissivity at the absolute temperature T, and r the volume resistivity of the metal at this temperature. Experimental observations upon platinum obtained by the use of radiation pyrometers confirmed the above theoretical relation. A table of corrections is given for converting temperatures observed with a radiation pyrometer sighted upon platinum to true temperatures. The following table represents the total emissivity of pure platinum as a function of the temperature:

°C	0	200	400	600	800	1000	1200	1400	1700
Emissivity	.030	.051	.070	.089	.108	.124	.140	.155	.175

THE EMISSIVITY OF METALS AND OXIDES, II: MEASUREMENTS WITH THE MICROPYROMETER.

By G. K. Burgess and R. G. Waltenberg.

THE micropyrometer may be used conveniently for the approximate determination of the monochromatic emissivities of metals, oxides, etc., in microscopic quantities at high temperatures. It is possible to determine to one per cent. the emissivity of a mass of 0.01 mg. having an area of 0.25 mm.^{2} and a thickness of 0.0005 mm. The determination of the temperature coefficient of emissivity is readily made, as well as the detection of variation of emissivity with change of state, as at the melting-point.

Assuming the emissivity for solid platinum is 0.33 for red light of wave-length $\lambda = 0.65\mu$ and 0.38 for $\lambda = 0.55\mu$, the following, among other results, have been obtained:

EMISSIVITIES OF METALS AND OXIDES WITH MICROPYROMETER.

Metals		Cu	Ag	Au	Pd	Pt	Ir	Rh	Ni	Co	Fe	Mn	Ti
$^{c}\lambda = 0.65\mu$	solid	.10	.04	.14	.33	.33	.30	.29	.36	.36	.37	.59	.63
	liquid	.15	.07	.22	.37	.38	...	.30	.37	.37	.37	.59	.65
$^{c}\lambda = 0.55\mu$	solid	.38	<.35	<.38	.38	.38	...	...	.44	...	...	...	.75
	liquid	.36	<.35	<.38	...	...	...	...	.46	...	...	...	.75

		Zr	Th	Y	Er	Be	Cb	V	Cr	Mo	W	U
$^{c}\lambda = 0.65\mu$	solid	.32	.36	.35	.55	.61	.49	.35	.39	.43	.39	.54
	liquid	.30	.40	.35	.38	.61	.40	.32	.39	.40	...	.34
$^{c}\lambda = 0.55\mu$	solid	...	.36	...	...	.61	.61	.29	.53	...	...	.77
	liquid	...	...	...	.30	.81	...	...	...	...	...	...

Oxides near freezing-points		NiO	CoO	Fe_3O_4	Mn_3O_4	TiO_2	ThO_2	Y_2O_3	BeO	CbO_2	V_2O_3	Cr_2O_3	U_3O_8
$^{c}\lambda = 0.65\mu$	solid	.89	.77	.63	...	.52	.57	.61	.37	.71	.69	.60	.30
	liquid	.68	.63	.53	.47	.51	.69	...	...	...	...	...	.31

For none of the metals examined was there a marked temperature coefficient in the range 900 to 2000° C., and for the most of them this coefficient is negligible, the emissivity usually agreeing also with the value at 20° C. For the white metals the emissivity usually shows very slight or no change at the melting-point, but for gold, silver, copper, and uranium there is a marked discontinuity with red light. For palladium there are anomalies in the behavior of the emissivity at the melting-point; and for platinum the fact that there is a change in emissivity (for $\lambda = 0.65\mu$) on melting would influence the constancy of the Violle standard of light.

STUDIES ON THE SILVER VOLTAMETER.*

By G. A. Hulett and G. W. Vinal.

A COMPARISON has been made of the silver voltameters and methods employed at the Bureau of Standards with the voltameters and methods used at Princeton University. For the details of the previous work at these two institutions reference is made to the *Bureau of Standards Bulletin*, vol. 9, pp. 151, 209, 493; vol. 10, p. 475, and *Transactions of American Electrochemical Society*, vol. 12, p. 257; vol. 22, p. 367. All the experimental data recorded in this paper were obtained in the Laboratory of Physical Chemistry of Princeton University.

A preliminary comparison of the voltameters, using the same electrolyte in all, showed a consistent difference of one part in ten thousand, the Bureau voltameters having the greater deposit. A systematic search for the cause of this difference showed it to be due to two factors: First, the differences in the method of preparing the porous cups; and, second, the differences in the method of washing the deposit.

The Bureau's porous cups were kept in silver nitrate between experiments and produced little change of acidity in the electrolyte of the voltameter, but the Princeton porous cups were usually washed free from the silver nitrate after each experiment and kept in distilled water. It was found in this case that the acidity of the voltameter electrolyte increased. The fact that the Bureau's porous cups were made by a different maker than for the

* Abstract of paper to appear in full in the *Bulletin of the Bureau of Standards.*

Princeton cups was without significance, since when the two different kinds were kept saturated with silver nitrate they produced identical results.

The practice of nearly all observers has been to continue the washing of the deposit until the presence of silver nitrate can no longer be detected in the wash waters by chemical tests, but many have taken the further precaution of allowing distilled water to stand on the deposit for a considerable period of time. As a test on the completeness of the washing, we compared the conductivity of the water before being put in the cup with its conductivity after it had stood in the cup for various periods of time. In every case the conductivity increased with time. It was at first supposed that this increase was due to entrapped silver nitrate gradually soaking out, as we could detect the silver in the water after allowing it to stand over night. All subsequent experiments, for which reference is made to the complete paper, showed that this is not the case, but rather that an electrolytic process was taking place by which the silver was passing into solution at the rate of about 0.006 mg. per hour from a four-gramme deposit of silver on platinum. To confirm this we were able to show by a galvanometer that a current actually passed from the silver through the water to the platinum. In washing the deposits over night this effect becomes appreciable. The work was closed with a final comparison of the voltameters in the light of our experiments, and usually good agreement was found.

Fire-damp Indicator. Anon. (*Sci. Amer.*, cxi, No. 7, 111.)—A new fire-damp indicator was recently demonstrated in London. The device is adapted to indicate the presence of fire-damp in coal mines. It is based on the well-known principle of catalytic combustion resulting from placing platinum black in certain explosive (inflammable?) gases. The device is in the shape of a torch with two differential thermo-electric couples connected in series with a sensitive galvanometer. Each thermocouple is embedded in a bead of porous material, one of which beads is impregnated with platinum black, so that in the presence of fire-damp it will become heated above the other and generate a thermo-electric current, which will deflect the galvanometer. In order to make the platinum black as sensitive as possible, each bead is heated by a resistance coil to the required temperature. As both of the beads are heated to the same temperature, there is no deflection of the galvanometer under normal conditions.

Action of Colloids on Radio-active Products in Solution. T. GODLEWSKI. (*Phil. Mag.*, xxvii, 618.)—It has been previously shown that the products of the active deposit of Ra in neutral, alkaline, or weakly acid solutions are in the colloidal state. It was also found that in acidulated solutions or in presence of polyvalent cations the products were deposited at the cathode almost exclusively, while in presence of polyvalent anions the anode is activated on electrolysis. Anomalous results were obtained with RaC, which in pure water solution appears to be deposited partly at the cathode and partly at the anode, although RaA appears at the anode only, and RaB at the cathode. Further experiments appear to explain this. When the atom of RaC arises from the RaB the recoil is only feeble, RaB emitting only a β particle. For this reason, if one of the atoms in the aggregate RaB which forms the centre of a positive hydrosol is transformed into RaC, it will not escape from its environment of RaB atoms, but will be carried with them to the cathode. We may, therefore, expect that only those RaC atoms go to the anode which manage to escape during their transformation, and also those which belong to groups in which the majority of the RaB atoms have already undergone transformation. Detailed experiments have been made on the influence of foreign colloids on the hydrosols of RaA, RaB, and RaC. The results show that the addition of a negative colloid (arsenious sulphide or platinum) in small quantity causes the products deposited at the cathode to diminish in amount and afterwards to disappear. Similarly, positive colloids (ferric oxide) when added in relatively small amount conduce to precipitation of RaA and RaC, which are among negative colloids; in higher concentrations positive colloids absorb them, thus inverting their signs. Radio-active products, as positive hydrosols, can be concentrated by filtration, since these hydrosols are entrained by filter-paper, owing to capillary action.

Durability of Taps for Benzine Tanks. ANON. (*Eng.*, xcviii, No. 2532, 63.)—Professor Alexander Baumann, of the experimental station for aëronautics and automobilism of the Technical High School at Stuttgart, has made some experiments on the durability of taps, greased and ungreased, when exposed to the flow of benzine. New taps were fitted into two vertical pipes, each three metres high; the upper portions of the pipes consisted of glass tubes, 4 mm. in internal diameter, behind which cardboard scales were fixed. By the aid of mechanism the two taps were opened and closed simultaneously, fifty times in each series, and observations were taken half an hour later of the sinking of the benzine level. The one tap was greased and the other not. The loss of benzine with the greased tap amounted to 5 mm. or less, and did not increase. With the ungreased tap the loss amounted to 145 mm., and rose in later trials to 1500 mm. Nothing is said as to the nature of the grease used; it is merely stated that it should be insoluble in benzine.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, November 18, 1914.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 18, 1914.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership, 4.

Mr. George R. Henderson, chairman of the Committee on Science and the Arts, introduced Mr. Arthur Atwater Kent, of Rosemont, Pa., and Mr. Elmer A. Sperry, of New York City, who had been recommended to the Board of City Trusts of Philadelphia for the award of the John Scott Legacy Medal and Premium, the former for his Ignition System, and the latter for his Gyro Compass. The Chairman then presented the medals to the recipients.

Dr. Dayton C. Miller, of the Case School of Applied Science, Cleveland, Ohio, was then introduced and presented an interesting communication on "The Photography and Analysis of Sound Waves." He discussed the wave theory of sound, and described, by means of models and lantern slides, the form of the waves of sounds composed of a fundamental tone and overtones. With the aid of lantern photographs, Dr. Miller described the phonodeik, an apparatus for obtaining photographic records of sound waves, and gave the results of experiments made in the Case School in analyzing sounds from the various musical instruments and from the human voice. He outlined the method of analyzing the records obtained with this apparatus by means of Fourier's theorem, and gave some of the mathematical results obtained. At the close of his remarks he showed on the screen impressions received in a projecting phonodeik from the voices of a number of persons in the audience, from a violin, and from a talking machine. In all cases the forms of the waves were clearly seen. The thanks of the meeting were extended to the speaker and to the artists and others who assisted in the demonstration.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, November 4, 1914.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 4, 1914.

MR. GEORGE R. HENDERSON, *Chairman.*

The following report was presented for final action:

No. 2584.—The Humphrey Pump.

Recommendation to award the John Scott Legacy Medal and Premium to Herbert Alfred Humphrey and Alberto Cerasoli, both of London, England, adopted.

R. B. OWENS,
Secretary.

AWARDS OF THE JOHN SCOTT MEDAL.

THE CITY OF PHILADELPHIA, acting on the recommendation of The Franklin Institute, has awarded the John Scott Legacy Medal and Premium to Elmer Ambrose Sperry, of New York, N. Y., for his Gyro Compass. On battleships under action the shifting of large masses of magnetic material precludes the use of the magnetic compass, and even on ordinary iron vessels the material of the ship and its disposition must be compensated for. The gyro compass is entirely non-magnetic and is unaffected by the proximity of iron. For some years Mr. Sperry has devoted practically his whole time to overcoming the numerous physical difficulties involved in the adaptation of a gyroscope to a ship's compass in the place of a magnetic needle. He has been able to make an instrument which automatically corrects for the speed and direction of the vessel, and which is unaffected by the rolling of the ship in a heavy sea. His compass may be made in the form of a master compass which may be made to actuate secondary or repeater compasses mounted in any desired part of the vessel. On naval vessels such an arrangement is very desirable, as the master compass may be installed behind heavy armor plate and protected from damage, and may still be available when all the secondary compasses are destroyed.

An award of the John Scott Legacy Medal and Premium has also been made to Arthur Atwater Kent, of Rosemont, Pa., for his Unisparker. The unisparker is an essential element of the Atwater Kent ignition system for automobiles, and consists of a contact-breaker, governor, and distributer, arranged in one structure. The contact-breaker is in the primary of a non-trembler coil circuit, and is so designed as to be operative only when the engine runs in one direction, thus preventing backfiring. The governor automatically advances and retards the spark according to the requirements of the engine. The distributer is in the secondary circuit of the coil and distributes the sparks to the several cylinders. All the parts of the device are especially designed for durability. The contact points are of tungsten and are of large area. The current in the primary circuit can be reversed at will, changing the polarity of the contacts and preventing their disintegration.

AWARD OF THE CERTIFICATE OF MERIT.

MR. W. A. BLONCK, of Chicago, Ill., has been awarded a Certificate of Merit for his Boiler Efficiency Meter. This device consists of two draft gauges, one of which is connected between the atmosphere and the boiler furnace and the other between the furnace and the breeching on the boiler side of the damper. The one gauge, therefore, indicates the resistance of the fire grate and the other that of the combustion chamber and tubes. Sliding indicators are attached to each gauge. To set the meter to give indications of the condition of the boiler to which it is attached, a test of the boiler is run to ascertain the best firing conditions, and the sliding indicators are set to the gauge levels. The fireman then endeavors to maintain these levels whenever the boiler is run. The meaning of deviations from these levels is inscribed on the sliding indicators.

SECTIONS.

Section of Physics and Chemistry.— A joint meeting of the Photographic Society of Philadelphia and of the Sections of Physics and Chemistry and of Photography and Microscopy of The Franklin Institute was held in the Hall of the Institute on Thursday, October 29, 1914, at 8 o'clock P.M., with Dr. Henry Leffmann, president of the latter section, in the chair. The minutes were approved as published.

C. E. Kenneth Mees, Sc. D., Director of the Research Laboratory of the Eastman Kodak Company, Rochester, N. Y., delivered a lecture on "The Physics of the Photographic Processs." The effect of exposure and development upon photographic materials was shown to be due to the granular structure of the latter, the light producing an exceedingly small change in each grain. The quantity of energy required to produce this change was considered. It was demonstrated that the properties of the sensitive material depend on the number of changed grains and on the energy expended, and that the sensitiveness and resolving power of the materials bear a direct relation to the size of the grains. A vote of thanks was extended to Dr. Mees, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A stated meeting of the Section was held in the Hall of the Institute on Thursday, November 5, 1914, at 8 o'clock P.M., with Dr. Harry F. Keller in the chair. The minutes of the previous meeting were read and approved.

Maximilian Toch, Ph.D., Director of the Research Laboratory of Toch Brothers, New York, N. Y., delivered a lecture on "Artistic Painting and the Secret of the Old Masters." The various mineral pigments and the one organic color, "madder lake," which were known to the masters of the Dutch and Italian schools from the fourteenth to the seventeenth century, were described, as were the precautions observed by these masters in mixing and applying their paints. The methods of distinguishing a genuine from a spurious painting were outlined. The effects of light and of atmospheric and chemical gases on various pigments were shown by means of experiments and lantern slides. Certain incompatibilities in the mixing of pigments were demonstrated experimentally. After an extensive discussion of the lecture, a vote of thanks was extended to Dr. Toch, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Mechanical and Engineering Section.—A meeting of the Section was held in the Hall of the Institute on Thursday, November 12, 1914, at 8 o'clock P.M., with Mr. George R. Henderson, president of the Section, in the chair.

Mr. George W. Fuller, C.E., Consulting Hydraulic and Sanitary Engineer, New York, N. Y., addressed the meeting on the subject of "Biochemical

and Engineering Aspects of Sanitary Water Supplies." The speaker dealt with the mooted question of the value of measurements of coli bacteria conditions of public water supplies, expressing his opinion that such measurements were almost impossible of correct interpretation. With the aid of lantern slides he illustrated the effect of methods of purification of public water by sedimentation, filtration, storage, etc., upon the death-rate from typhoid fever in the largest American cities. He stated that too much stress should not be laid upon the influence of the public water supply alone upon the public health, but that other factors, such as general sanitation and the carrying of disease germs by the common fly and the mosquito, should be taken into consideration. Mr. Fuller stated that he had embodied his opinions on the biochemical and engineering aspects of the subject of public water supplies in a written communication, which he would refer to the Institute.

WILLIAM E. BULLOCK,
Acting Secretary.

LECTURE ON ARCHITECTURAL ACOUSTICS.

DR. WALLACE C. SABINE, Dean, The Graduate School of Applied Science, Harvard University, Cambridge, Mass., delivered a lecture, entitled "Architectural Acoustics," in the Hall of the Institute on Friday evening, November 6. Dr. Sabine gave the results of his investigations, extending over a period of some eighteen years, to determine the absorbing power of the various materials which enter into the construction and furnishing of an auditorium. He spoke of how, in the early stages of his work, these investigations were confined to the determination of the coefficient of absorption for sound having the pitch of violin C, but how they were later extended from a range of pitch from three octaves below to three above violin C. He described how other aspects of the acoustic problem, such as interference, resonance, and echo, presented themselves and were taken up in his work simultaneously. Dr. Sabine called attention to the incompleteness of his measurements on account of the vast amount of labor involved in obtaining them, and suggested the further extension of this work by architects as opportunities presented themselves.

WILLIAM E. BULLOCK,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 11, 1914.*)

RESIDENT.

DR. GEORGE S. CRAMPTON, 1700 Walnut Street, Philadelphia, Pa.
MR. JOHN J. KOHLER, 4121 North Sixth Street, Philadelphia, Pa.
MR. GEORGE F. SCHAEFER, 16 North Sixty-first Street, Philadelphia, Pa.

NON-RESIDENT.

MR. GEORGE T. CLARKE, Leland Stanford Junior University, Stanford University, Cal.

CHANGES OF ADDRESS.

MR. M. J. CAPLES, 50 East Broad Street, Columbus, Ohio.
MR. SAMUEL S. FELS, Thirty-ninth and Walnut Streets, Philadelphia, Pa.
MR. L. J. R. HOLST, 5406 Baltimore Avenue, Philadelphia, Pa.
MR. EDWARD A. STROUD, Strafford, Pa.
MR. ERNEST STUTZ, 87 Nassau Street, New York, N. Y.
MR. SIMEON TRENNER, 817 Crescent Place, Chicago, Ill.
MR. F. R. WADLEIGH, 426 Real Estate Trust Building, Philadelphia, Pa.
DR. WILLIAM J. WILLIAMS, 1305 Foulkrod Street, Frankford, Pa.

NECROLOGY.

Dr. William Lefland Dudley was born at Covington, Ky., in 1859. He was educated in the common schools of his native town and at the University of Cincinnati, from which he was graduated Bachelor of Science in 1880. He continued his studies at the Miami Medical College, and received his degree of Doctor of Medicine in 1885. From 1879 to 1886 he was a professor of chemistry in the Miami College. In 1895 he was made Dean of the Medical Department of Vanderbilt University, and he occupied that position until two years ago, when he was compelled by failing health to resign. He was the discoverer of the physiological properties of X-rays and of the luminosity of comets, and was the author of valuable papers on chemical subjects. He was a director of the Tennessee Centennial Exposition in 1897 and a member of the Executive Committee of the Eighth International Congress of Applied Chemistry in 1912 and vice-president of the Section on Law as Affecting Chemical Industry. He was a prominent member of the American Chemical Society and the American Association for the Advancement of Science. He was elected to membership in the Institute in 1913.

LIBRARY NOTES.

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AUSTEN, SIR W. C. ROBERTS-.—Record of His Work: Being a Selection of Addresses and Metallurgical Papers. 1914.
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The Most Important Question of the Age: Is the Efficiency of a Thermodynamic Reversible Cycle Independent of the Working Medium? by Jacob T. Wainwright. 8 pages, 8vo. Chicago, 1914.

Stresses Due to Shrinkage of Ferro-concrete. CONSIDÈRE. (*Comptes Rendus,* clviii, 1096.)—This criticises the views of Rabut, who holds that the values of shrinkage-stresses given by the *Commission officielle du Ciment Armé* are excessive. Mortars and concretes dilate in water and contract in air. O. Graf's results are quoted and compared with recent experiments at the *Ecole des Ponts et Chaussées,* which show that after 54 months' immersion the shrinkage decreased from 0.370 mm. to 0.130 mm. On exposure to air the shrinkage increased from 0.130 mm. to 0.430 mm. in 35 months, and at such a rate as to corroborate the shrinkage given by Graf as 0.512 in six years. Alternating stresses in concrete have the same effects as in metals, but the stresses due to shrinkage and dilatation do not vary rapidly or much in comparison with those due to temperature and live loads. The author doubts if the matter is susceptible of analysis, and recommends direct-experiments on stresses in actual constructions.

CURRENT TOPICS

Synthesis of Ammonia by Means of Aluminum Nitride. C. MATIGNON. (*Chem. Zeit.*, xxxviii, 894.)—Serpek has shown that when a current of nitrogen is passed through a mixture of alumina and carbon at 1800° C. the alumina is rapidly converted into aluminum nitride:

$$Al_2O_3 + 3C + Na_2 = Al_2N_2 + 3CO - 187.6 \text{ cal.}$$

The heats of formation of the nitrides of the following metals, calculated on Na_2, are: Mg, 119.7; Ca, 111.2; Si, 90; Al, 110 cal. Aluminum combines directly with atmospheric nitrogen when introduced at a high temperature into a flask containing nitrogen, or if a mixture of aluminum powder and carbon is strongly heated and a current of nitrogen introduced through a carbon tube within the mass. A temperature of 2000° C. is easily obtained in this way. Serpek's process can be accelerated, and effected at 1500° C. by the aid of the catalytic action of hydrogen and iron. In experiments at 1500° C., lasting one hour, in the presence of hydrogen, the product contained 12.85 per cent. N; in the presence of iron, 7.7 per cent., and in the presence of both hydrogen and iron, 27.07 per cent. Bauxite containing iron oxide can therefore be used for the process, and subsequent decomposition of the nitride yields ammonia and pure alumina. The nitride is heated under pressure with a solution of sodium aluminate of 20° to 21° Be. (sp. gr. 1.162 to 1.171), and the alumina is then precipitated by adding some precipitated alumina, the solution being used again without further concentration. The cost of preparing alumina from the nitride in this way is about half that of preparing it from bauxite by heating under pressure with caustic soda and sodium aluminate of 40° Be. (sp. gr. 1.383). When the process is worked solely for the production of ammonia, the alumina is not purified, and the decomposition of the nitride is simpler. A furnace for the manufacture of aluminum nitride by Serpek's process comprises a fixed chamber arranged between two inclined rotating cylindrical chambers which open into it. The lower of these rotating chambers contains a resistance and forms an electric furnace; the lining is of aluminum nitride. Bauxite is fed into the upper end of the rotating chamber and passes downward through the chambers, mixing with carbon which is fed into the fixed chamber, and meeting a current of nitrogen which is admitted at the lower end of the electric furnace. The carbon monoxide formed in the reaction is burned at the lower end of the upper chamber, and serves to preheat the bauxite. Each of the rotating chambers is 25m. long and a current of 10,000 ampères at 230 volts is used.

Quantity and Character of Creosote in Well-preserved Timbers. G. ALLEMAN., (*Proc. Amer. Wood Preservers' Assoc.*, 88.)—The creosote oils extracted from timber which had been in use many years showed an average of 32.9 per cent. distillate below 270° C. and 66.8 per cent. oils of high boiling-point. The defects of most modern creosote preservatives are deficiency in basic oils of high boiling-point and the substitution for these of tar or other viscous substances. Under proper conditions of distillation a stable, heavy creosote oil (sp. gr. 1.10) could be manufactured from coal tar, containing nothing which boils below 210° C., for general purposes not more than 50 per cent. of the total should distil below 315° C., and for wood-paving blocks not more than 35 per cent. The qualities demanded are penetrating power, stability, and preservative and water-proofing value. All these are possessed in a high degree by pure, heavy, creosote oil. Tar has a very low penetrating power, even when injected at a high temperature, and wood treated with a mixture shows a separation of the components (oil, tar, and carbon) at the margins of the close-grain rings. As regards stability, losses occur owing to volatilization, extraction by water, and crystallization in wood impregnated with light creosote oils. Preservative value may depend upon direct antiseptic action or permanent adhesion of a stable oil-coating to the walls of the minutest cells; external filming without penetration is of little account. In the light oils the antiseptic constituents predominate, but are volatile and largely soluble in water. The heavy oils are sufficiently rich in the higher homologues of cresols, both these and the protective oils being far more stable. Water-proofing depends on the complete coating of the cell walls with an oily deposit which excludes moisture.

Surface Film on Polished Metals. G. T. BEILBY. (*Roy. Soc. Proc.*, Ser. A, 89, 593.)—Shows that the minute pits in a polished surface of copper are covered by a transparent or highly translucent film which crosses the empty pit without any support from below. By suitable methods of polishing, the skin developed on the surface may be raised to a maximum thickness or reduced to a minimum. Photomicrographs in natural colors accompany the paper, and show the bluish film crossing the pits, and the empty pits after the film has been dissolved by a 10 per cent. solution of ammonium persulphate acting for twenty or thirty seconds. The thickness of the film is probably of the order of 10 to 20 $\mu\mu$.

Recent Developments of the Hydraulic Reaction Turbine. H. B. TAYLOR. (*Gen. Electr. Rev.*, xvii, 533.)—Treats under the following captions: Design and testing of a turbine; Mechanical features of turbine construction; General arrangement of unit; Volute casing; Draught tubes; Supporting rings and face plates; Pressure thrust bearing; Roller bearing; Mechanical details; and Speed regulation.

Causes of Discoloration of Organic Fibres (e.g., Bleached Cotton). B. HAAS. (*Papierfab.*, xii, 891.)—The tendency of bleached cellulose to discoloration was studied with samples of pure cotton cloth: (*a*) American, (*b*) Egyptian. A most useful test consisted in boiling the fabric with distilled water, draining, and exposing to light; in many cases the discoloration was already apparent in the aqueous extract. Fabrics bleached with bleaching powder solution showed the greatest tendency to discoloration; those bleached by electrolytic liquor were better, and those bleached with sodium peroxide were almost stable in color. Another test consisted in damping the cellulose and subjecting it in small heaps to a retting process with a thermometer embedded in the heap; lack of purity and tendency to discoloration were then indicated by a greater or less rise of temperature. Unbleached cottons responded to this test in the highest degree, but the bleached fabrics also followed in the order of bleaching processes mentioned above. In all cases the Egyptian samples showed more distinct reactions than the corresponding American samples. The inferior results obtained with bleaching powder liquor are attributed partly to the deleterious action of the calcium chloride and free lime, and partly to the fixation of alkaline earth compounds on the fibre in an insoluble condition; moreover, the benefit to be derived from the use of soft water in the bleaching process is forfeited. In the electrolytic bleach the sodium chloride and chlorate may have a minor deleterious action, but the fixation of insoluble calcium compounds is avoided. Discoloration is due to the presence of impurities of original or secondary nature, mechanically or chemically combined with the true cellulose, and to the auto-oxidation or alteration of these impurities. The nearer the cellulose to complete purity the more stable is the bleached color.

Cooling of Spheres. F. VERCELLI. (*N. Cimento*, vi, Ser. 6, 427.)—Two spheres of different substances but equal radius, cooled from the same initial temperature until they attain a given final temperature at the centre, have coefficients of thermal conductivity which are directly proportional to the density and specific heat, and inversely proportional to the time required for cooling. There is described a method governed by rigorous formulæ and involving the use of elliptic functions.

Platinum Discovered in Germany. ANON. (*Sci. Amer.*, cxi, No. 7, 111.)—Electrical engineers will be interested to learn that extensive deposits of platinum have been discovered at Wenden, in Westphalia, and that they are soon to be worked on a large scale. Hitherto we have had to depend almost entirely upon the mines in the Ural Mountains for this metal which is so indispensable in electrical apparatus. Fully 95 per cent. of the world's production of platinum has come from Russia.

Manufacture of Galalith. G. BONWITT. (*Z. Angew. Chem.*, xxvii, 2.)—Galalith is prepared from a specially pure casein, from sweet milk perfectly freed from fat by centrifuging; the casein is precipitated by rennet, since acids make it quite unsuitable. The curd is drained and dried, forming lumps 8 to 12 mm. thick. These are ground, first in a fluted-roller mill, then in a porcelain-roller mill, to a gritty meal. The meal is moistened with a given quantity of water, and must then be worked up within twelve hours, otherwise it begins to ferment. The moist meal, colored as required, is worked up between steel helices to a plastic mass, which is then hot-pressed in hydraulic presses. The pressed cake is hardened in a solution of formaldehyde of accurately adjusted concentration, which is circulated continuously to avoid the formation of paraformaldehyde. The length of treatment varies from two to thirty weeks, according to the thickness of the articles; the rooms are heated and well ventilated. Drying is effected in a current of warm air. The hardening takes away the extreme brittleness of the casein and imparts the qualities of natural horn. Galalith is a good electrical insulator; a plate 2 mm. thick will resist 16,000 volts. The specific gravity is 1.317 to 1.35 (celluloid, 1.34 to 1.40). The hardness is 2.5 (celluloid, 2). It resists oily liquids and acids, but is swelled by alkaline liquids. Its chief drawback is its hygroscopicity; it absorbs 30 per cent. of its weight of water in twelve days. It is not elastic like celluloid, and breaks when slightly bent. On account of its tendency to flake it cannot be worked as well as celluloid, and sheets cannot be prepared less than 2 mm. thick. It is chiefly used in the turning trade and for the manufacture of buttons, combs, and piano-keys; it does not turn yellow.

Three-phase Towing Locomotives for the Panama Canal. ANON. (*Electr. Rly. Journ.*, xliii, 835.)—Forty locomotives have been built by the General Electric Company, with tractive power up to 47,500 pounds. Four of these, two on each side, will propel steamships through the locks. No vessel is allowed to go through the locks under her own power. The locomotive is propelled by a rack rail while towing at a speed of two miles per hour; when running idle the rack pinion is released and the speed increased to five miles per hour. The locomotive is driven by two 75-horse-power motors; in the centre there is a vertical windlass with drum, the capacity of which is 800 feet of one-inch steel hawser cable.

Recent Advances in the Manufacture and Use of Fertilizers. A. STUTZER. (*Chem. Zeit.*, xxxviii, 310.)—Potassium salts have recently been used for the top dressing of cereals, and are better adapted than kainit for this purpose. Artificial nitrogen compounds from atmospheric nitrogen—nitrolim, calcium nitrate, ammonia, nitric acid, and urea—are being increasingly used in Germany.

Notes on Sulphite Pulp Manufacture. A. FROHBERG. (*Chem. Zeit.*, xxxviii, 126.)—The idea that the system of digesting with indirect steam is superior to the direct steam system is not correct. When boiling with live steam the circulation is much better and the mixing of the "acid" and rise of temperature are more rapid: Below 100° C. adsorption phenomena occur, the colloidal wood adsorbing sulphurous acid from the liquor; consequently high concentration and maximum surface development are favorable. The chief objection to the direct steam system is the necessity for blowing over large quantities of liquor, owing to the dilution. Thus liquors driven over and regenerated contain organic matters which weaken the efficiency of the "acid" by promoting the decomposition of the sulphurous acid into trithionic acid. It is better to separate the gases from the liquors blown over and utilize them separately. The organic matters in the "acid" may be determined colorimetrically after driving off the sulphurous acid, or oxidizing by hydrogen peroxide. Acid produced in the towers at 3 to 3.2 per cent. strength can be enriched up to 4.5 per cent. by a systematic regeneration process. Blowing over also causes loss of heat; the necessity for blowing over increases with steam of low heat capacity; the use of superheated steam up to 220° C. affords considerable economy in this direction. Good distribution of superheated steam is essential; a maximum digestion temperature of 145° C. does not injure the quality of the cellulose. The formation of sulphur trioxide is at a maximum at 400° to 500° C.; at 900° to 1000° C. the sulphur trioxide is decomposed again into sulphur dioxide and oxygen. The furnace must, therefore, be worked as hot as possible in order to obtain gases rich in sulphur dioxide; the gases must be immediately cooled by direct spraying with water to reduce the temperature to 90° to 100° C.

Mercury-vapor Lamp for Inspecting Translucent Products. ANON. (*Electr. World*, lxiv, No. 2, 78.)—Cube sugar and ivory piano keys are inspected under artificial illumination produced by mercury-vapor lamps with greater speed and accuracy than can be attained in ordinary daylight. Raw sugar is a brown substance, while the refined product is pure white, its whiteness being due to the same cause as the whiteness of snow, since both consist of small transparent crystals. Any impurity in sugar is manifested by changing the white to a shade of yellow. To detect impurities, plates of the crystallized sugar one inch thick are examined by looking through them toward a mercury-vapor lamp. When thus viewed the yellow impurities stand out clearly in this bluish-green light. The color of ivory varies from the outside to the centre of the tusk to such an extent that manufacturers sort the pieces into sixteen different shades. Formerly this sorting could be done only in bright daylight, but with the light of the mercury-vapor lamp grading can be done without limitation at any hour of the twenty-four.

INDEX TO VOL. CLXXVIII.

Acoustics, Architectural (Sabine), 786
Aërial Navigation:
Durand, W. F., The screw propeller: with special reference to aëroplane propulsion, 259
Wright, Orville, Stability of aëroplanes, 249
Zahm, A. F., Wing data and analysis for staggered biplane, 663
Aëroplane propulsion, The screw propeller with special reference to (Durand), 259
Aëroplanes, Stability of (Wright), 249
Aldehydes, Occurrence of, in garden and field soils (Schreiner and Skinner), 329
Alternating-current lines, composite, The computation of (Kennelly), 287
Axles, heat-treated, Internal stresses in (Wille), 561

Bacon, Raymond F.: Progress in industrial fellowships, 623
Biplane, staggered, Wing data and analysis for a (Zahm), 663
Bitner, R. E., W. R. Ham, and R. B. Fehr: A photographic null method for measuring absorption in the ultra-violet, 299
Book Notices:
Arndt, K.: A popular treatise on the colloids in the industrial arts, 509
Bailey, H. S., and H. P. Cady: Qualitative analysis, 119
Benson, H. R.: Industrial chemistry, 120
Billiter, J.: Die elektrolytische alkalichloridzerlegung, vol ii, 119
Hönigschmid, O.: Karbide und silizide, 119
Horner, J. G.: Practical iron founding, 509
Stoddard, J. T.: Introduction to organic chemistry, 654
Tennant and Ward's Manuals of photographic procedure, 654
Verfasser, J.: The half-tone process, 655
Wysor, H.: Metallurgy, 655
Brady, E. J. and Herbert E. Ives.: An apparatus for the spectroscopic synthesis of color, 89

Catenary construction of the New York, Westchester and Boston Railway (Withington), 705
Chemistry, Photographic, Recent advances in (Leffmann), 743
Clark, Walton: The Franklin Institute and the State, 221
Coblentz, W. W.: Exudation of ice from stems of plants, 589
Color, Spectroscopic synthesis of (Ives and Brady), 89
Correspondence:
Definitions of the fundamental units of electrical measurement (Mendenhall), 215
The Franklin Medal (Outerbridge), 654
International Electrical Exhibition, 1884, and thirtieth anniversary (National Electric Light Association), 504
Current Topics, 84, 87, 88, 96, 99, 100, 104, 121, 122, 160, 179, 180, 194, 225, 226, 232, 237, 238, 242, 243, 258, 286, 297, 298, 343, 344, 355, 356, 374, 375, 416, 434, 464, 482, 500, 510, 511, 560, 588, 621, 622, 643, 644, 657, 658, 679, 680, 749, 750, 776, 781, 782, 793, 794
Cushman, Allerton S.: Modern research in the metallurgy of iron, 133

Durand, W. F.: The screw propeller: with special reference to aëroplane propulsion, 259

Electrical units, Definitions of (Mendenhall), 215
Engineer, The, as a factor in modern progress (Humphreys), 227

Fehr, R. B., W. R. Ham, and R. E. Bitner: A photographic null method for measuring absorption in the ultra-violet, 299
Fernald, R. H.: Producer gas from low-grade fuels, 161

FRANKLIN INSTITUTE:
Award of the Elliott Cresson Medal to distinguished scientists and technologists, 105
Celebration of the thirtieth anniversary of the International Electrical Exhibition, held in Philadelphia in 1884, 195
Certificate of merit awarded to W. A. Blonck for his boiler efficiency meter, 784
Franklin Medal, 502
Lecture on architectural acoustics (Sabine), 786
Library, Some recent additions, 357
Library notes, 116, 239, 505, 648, 787
Membership notes, 115, 239, 357, 501, 647, 786
Science and the Arts Committee: Meetings: June 3, 1914, 115; September 2, 1914, 501; October 7, 1914, 645; November 4, 1914, 783
Scott Medal awarded to Arthur Atwater Kent for his unisparker, 784
Scott Medal awarded to Elmer A. Sperry for his gyro compass, 784
Sections, Meetings: 645, 785
Stated meetings: October 21, 1914, 645; November 18, 1914, 783
Franklin Institute and the State (Clark), 221
Franklin Medal, 502
Franklin Medal (Outerbridge), 654

Gas works by-products, Recovery of (Tutwiler), 383
Gasoline, motor, The problem of (Winkler), 97

HAM, W. R., R. B. FEHR, and R. E. BITNER: A photographic null method for measuring absorption in the ultra-violet, 299
HERING, RUDOLPH: Sewage treatment, 417
HUMPHREYS, ALEX. C.: The engineer as a factor in modern progress, 227
HUMPHREYS, W. J.: The thunderstorm and its phenomena, 517, 751

Ice, Exudation of, from stems of plants (Coblentz), 589
Illumination, Recent developments in the art of (Millar), 435
Industrial fellowships, Progress in (Bacon), 623
Internal stresses in heat-treated axles (Wille), 561
International Electrical Exhibition, 1884, and thirtieth anniversary (National Electric Light Association), 504
International Electrical Exhibition, 1884, Celebration of the thirtieth anniversary (Franklin Institute), 195
Iron, Modern research in the metallurgy of (Cushman), 133
IVES, HERBERT E., and E. J. BRADY: An apparatus for the spectroscopic synthesis of color, 89

KENNELLY, A. E.: The computation of composite alternating-current lines, 287

LEFFMANN, HENRY: Recent advances in photographic chemistry, 743
Locomotive superheaters and their performance (Young), 1, 181

MARRIOTT, ROSS W. and JOHN A. MILLER: The quality of the twenty-four-inch objective of the Sproul telescope as determined by Hartmann tests, 465
MENDENHALL, T. C.: Definitions of the fundamental units of electrical measurement (correspondence), 215
MILLAR, PRESTON S.: Recent developments in the art of illumination, 435
MILLER, JOHN A., and ROSS W. MARRIOTT: The quality of the twenty-four-inch objective of the Sproul telescope as determined by Hartmann tests, 465

National Electric Light Association, International Electrical Exhibition, 1884, and thirtieth anniversary (correspondence), 504
New York, Westchester and Boston Railway, Notes on the catenary construction of, (Withington), 705
NORTHRUP, EDWIN F.: Resistivity of pure silver, solid and molten, 85

OUTERBRIDGE, ALEX. E.: JR.: The Franklin Medal (correspondence), 654

Photographic chemistry, Recent advances in (Leffmann), 743
Plants, Exudation of ice from stems of (Coblentz), 589
Producer gas from low-grade fuels (Fernald), 161
Publications received, 120, 241, 373, 510, 656, 792

RECKLINGHAUSEN, MAX VON: The ultra-violet rays and their application for the sterilization of water, 681
Resistivity of pure silver (Northrup), 85

SABINE, WALLACE C.: Architectural acoustics, 141
SCHREINER, OSWALD, and J. J. SKINNER: Occurrence of aldehydes in garden and field soils, 329
Screw propeller: with special reference to aëroplane propulsion (Durand), 259
Sewage treatment (Hering), 417
Silver, pure, Resistivity of (Northrup), 85
SKINNER, J. J., and OSWALD SCHREINER: Occurrence of aldehydes in garden and field soils, 329
Soils, Occurrence of aldehydes in (Schreiner and Skinner), 329
Stability of aëroplanes (Wright), 249

Telescope, Sproul, The quality of the twenty-four-inch objective of the (Miller and Marriott), 465
Thunderstorm, The, and its phenomena (Humphreys), 517, 751
TUTWILER, C. C.: The recovery of gas works by-products, 383

Ultra-violet light, Photographic null method for measuring absorption in the (Ham, Fehr, and Bitner), 299
Ultra-violet rays and their application for the sterilization of water (Recklinghausen), 681
U. S. Bureau of Standards, Notes, 101, 233, 345, 483, 633, 777

Water, sterilization of, Ultra-violet rays and their application for the (Recklinghausen), 681
WILLE, H. V.: Internal stresses in heat-treated axles, 561
Wing data and analysis for a staggered biplane (Zahm), 663
WINKLER, JOHN: The problem of motor gasoline, 97
WITHINGTON, SIDNEY: Notes on the catenary construction of the New York, Westchester and Boston Railway, 705
WRIGHT, ORVILLE: Stability of aëroplanes, 249

YOUNG, C. D.: Locomotive superheaters and their performance, 1, 181

ZAHM, A. F.: Wing data and analysis for a staggered biplane, 663

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